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# Re-examining international spillovers: An Asian perspective

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ABSTRACT

This study investigates the transmission and the business cycle implications of Chinese export shocks to other Asian economies. Based on a panel vector autoregression (PVAR) model, we provide evidence that a positive export shock originating from China simultaneously stimulates aggregate demands for both China and other Asian economies. The PVAR model takes into account three main sources of potential interactions among ten Asian economies. Simulations from a two-country DSGE model featuring endogenous trade links suggest that positive trade spillover is essential to explain the macroeconomic comovement pattern. Our findings further indicate the importance of the Chinese economy to business cycle synchronization.

## 1. Introduction

China's rising importance to the global economy in the last 30 years has attracted wide research interest in the fields of international trade and financial studies. Its role in the expansion of global economic integration is substantial. The US-China trade tension and the Covid outbreak did not affect this fact, as the Chinese exports grew rapidly during the pandemic period, with the exported value of goods in 2021 being 30% higher than in 2019.[1] In a period of less than 15 years it is expected to be the world's largest economy (Zenglein & Holzmann, 2019). One of the basic features of this dynamic process is the export-oriented development strategy of not only China, but of the whole Asia Pacific region (World-Bank, 2020). For this broad group of countries the importance of high productivity and the maintenance of upward trends in demand has increased, given the slow recovery in the US and the current Eurozone anaemic growth rates. The Regional Comprehensive Economic Partnership (RCEP) agreement can be viewed as a recognition of this need.[2]

This study examines the trade links between China and its principal Asian trading partners by investigating the impact of a Chinese export shock on the major Asian economies. Given the predominant exchange rate stability, the progress of financial liberalization and the important role of trade in the propagation of shocks (Ferreira & Trejos, 2022), we also evaluate the impact upon China's domestic economy. As a first step, we estimate a 5-variable panel VAR for China and its major Asian trading partners assuming dynamic and static interdependencies, as well as heterogeneities among the examined countries. According to our findings, a Chinese export shock affects all countries in our sample, leading to a comovement pattern between China and its trade partners.

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[1] The Chinese export rose from 2499 trillion US dollars in 2019 to 3365 in 2021. Source of data: Statista https://www.statista.com/statistics/263661/export-of-goods-from-china/.

[2] The agreement would cover 30% of the world's population, contribute about 30% of global GDP, and account for a quarter of global trade in goods and services. Source of data: Association of Southeast Asian Nations.

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However there are some quantitative differences regarding the effect on each individual country. We further show that the Chinese export shock can be a major driver of business cycles for Asian economies.

We then model the international trade links using a two-country Dynamic Stochastic General Equilibrium (DSGE) model. The model features endogenous trading activities between a home country (i.e. China) and a foreign country (i.e. an Asia Pacific country).[3] We show that in a two country environment, an export shock hitting China leads to an increase of imports from trading partners which further stimulates aggregate demands of the latter. This theoretical finding highlights the role of the trade spillover channel for explaining the macroeconomic comovement pattern found in the empirical analysis.

Our results can be interpreted in two ways. Given that Chinese exports might be considerably affected by demands from advanced economies, our results suggest that China plays as a nexus to transmit spillover from advanced economies to emerging markets.[4] Alternatively, one may interpret that changes of export in China due to development of domestic market, such as adoption of advanced technology, also spread effects on other emerging markets. Since we identify that the export shock propagates as an aggregate demand shock leading to co-movement in output and inflation, we argue that the domestic advance of productivity–a supply-sided factor–is unlikely to be the primary force driving our results. Overall, the theoretical and empirical analysis together imply an important role of China in promoting the business cycle synchronization either directly or indirectly in the Asia Pacific region.

Earlier evidence has indicated the role of international trade as a major determinant of business cycle comovement (Baxter & Kouparitsas, 2005). Given the ongoing developments of international investments in trade and economic integration (Jackson & Shepotylo, 2021), we investigate the quantitative effects of a positive export shock not only on China but also on its main Asian partners which constitute an important component of the global supply chain (Baldwin & Lopez-Gonzalez, 2015; Jiang et al., 2019). Moreover, we further provide explanations regarding the heterogeneous pattern in the spillover effects, which depends on the trade balance positions and degree of openness.

In addition to the international trade and business cycles literature, the present study builds on two branches of literature. The first part examines the process of shock transmission from China's (real and financial) sectors to other economies. Inoue et al. (2015) study the effects of Chinese negative growth shock. Working upon a GVAR model, their findings suggest that Asian economies are significantly affected. Interestingly, the degree of interconnectedness between Asian economies and China has been increased over the last decade. This finding reflects the above-mentioned trends on the increasingly significant role of China. Using the same empirical framework, Cashin et al. (2014) report similar results regarding the ASEAN-5 economies which are the most strongly affected by a Chinese growth slowdown. Feldkircher and Korhonen (2014) focus on a positive shock to the Chinese output, confirming the large influence on other economies. They also examine the impact of a real appreciation of the RMB with the findings being consistent with a decrease of economic activity in both China and its major exporting partners. Cesa-Bianchi et al. (2012) compare the long-term impact of a Chinese and a US GDP shock. Among their outcomes they support the view that, due to the increased trade relations between Latin America and China, the role of the latter has become more important than the US. In terms of monetary policy, Pang and Siklos (2016) report significant spillovers from China to the US, emphasizing the important role of the People's Bank of China in mitigating the impact of the 2008–9 global financial crisis. On the other hand, Cho and Kim (2021) examine the Chinese monetary policy shocks to other East Asian countries.

The second branch of literature is related to theoretical studies examining the Chinese economy. We differentiate from papers that have exclusively focused on China (Chang et al., 2015; Dai et al., 2015; Gu et al., 2014; Li & Liu, 2017; Zhang, 2020) by developing a two-country DSGE model in order to capture the cross-country spillovers. This type of modelling has gained popularity especially among policy institutions like central banks and IMF (Coenen et al., 2018; De Walque et al., 2017; Kumhof et al., 2010). In particular, we incorporate in the model a trade link between China and its trading partners, which allows us to provide a theoretical explanation for the empirical findings.

Our contribution is twofold. Firstly, we expand the literature that empirically examines the shock transmission process. We do this by employing a panel VAR analysis and imposing a specific identification structure. We also test the validity of the identifying restrictions. To the best of our knowledge, this is the first study doing this kind of VAR analysis accompanying by a testing procedure. From this part, we provide evidence on the international trade links and the cross-country spillovers between China and its major Asian trade partners. Secondly, based on the panel VAR evidence, we build a two-country DSGE model to provide a theoretical explanation for the empirical findings. Once more, this is the first study to combine empirical analysis that captures the all the cross-sectional linkages along with a solid theoretical model that takes into account two different economic entities. Our results have important policy implications. The disturbance in Chinese exports could generate far-reaching impacts on the Asia Pacific region. Specifically regarding the trade tension between the US and China, its effects could spread to other Asian economies whose exports are closely related to China, implying potential indirect effects on other Asian economies due to the complementary trade structure between China and its trade partner. Our results also shed light on the RCEP agreement. With a tight trade link between China and Asia Pacific countries, the former could be more likely to play as a nexus of international spillover and contribute to global post-pandemic recovery.

The rest of the paper is structured as follows. Section 2 discusses the econometric model along with the results. Section 3 describes the structure of the DSGE model and simulation results. Section 4 concludes.

[3] We consider the same structure for both economies but calibrated based on different data. We also consider different trilemma positions faced by the home and the foreign countries. However, results based on the alternative model are not supported by our empirical evidence.

[4] Arezki and Liu (2020) find that the international spillover largely runs from advanced economies to emerging markets. Our finding suggests that China contributes to the transmission of the international spillover.

## 2. Empirical analysis

### 2.1. Model and results

The present analysis is based on a Panel VAR methodology. In general, PVARs are becoming an increasingly popular tool for examining the interactions of several entities. The main advantage over traditional structural VAR is the addition of a cross-sectional structure. Compared with other VAR modelling approaches, like GVARs (Pesaran et al., 2004) that impose a particular structure on the interdependencies, PVARs are able to capture a greater variety of potential interlinkages. This is a significant property that allows us to assess and test the potential interconnectivity and spillovers among the examined countries. The terminology that we use thereafter is based on Canova and Ciccarelli (2013) who provide an excellent survey of the recent advances in PVARs.

Assuming $y_{it}$ as a vector of $G$ dependent variables captured for country $i$, $i = (1, \dots, N)$ at time $t$, $t = (1, \dots, T)$ with $l$ lags $(l = 1, \dots, L)$, we can compactly define the panel VAR as:

$$\begin{aligned} y_{it}c = {} & A^1_{i1t} y_{1t-1} + \cdots + A^L_{i1t} y_{1t-L} + A^1_{i2t} y_{2t-1} + \cdots + A^L_{i2t} y_{2t-L} + \cdots \\ & + A^1_{iNt} y_{Nt-1} + \cdots + A^L_{iNt} y_{Nt-L} + e_{it} \end{aligned} \tag{1}$$

where $A^L_{it}$ are $G \times NG$ matrices and $e_{it}$ are the error terms. These error terms are normally distributed as $N \sim \left(0, \Sigma_{ii}\right)$ with $\Sigma_{ii}$ $G \times G$ covariance matrices. Error terms are not correlated over time. Assuming for a while that there is no exogenous variable, the model can be written as:

$$\begin{aligned} \begin{pmatrix} y_{1t} \\ y_{2t} \\ \vdots \\ y_{Nt} \end{pmatrix} = {} & \begin{pmatrix} A^1_{11t} & A^1_{12t} & \cdots & A^1_{1Nt} \\ A^1_{21t} & A^1_{22t} & \cdots & A^1_{2Nt} \\ \vdots & \vdots & \ddots & \vdots \\ A^1_{N1t} & A^1_{N2t} & \cdots & A^1_{NNt} \end{pmatrix} \begin{pmatrix} y_{1t-1} \\ y_{2t-1} \\ \vdots \\ y_{Nt-1} \end{pmatrix} + \cdots + \\ & \begin{pmatrix} A^L_{11t} & A^L_{12t} & \cdots & A^L_{1Nt} \\ A^L_{21t} & A^L_{22t} & \cdots & A^L_{2Nt} \\ \vdots & \vdots & \ddots & \vdots \\ A^L_{N1t} & A^L_{N2t} & \cdots & A^L_{NNt} \end{pmatrix} \begin{pmatrix} y_{1t-L} \\ y_{2t-L} \\ \vdots \\ y_{Nt-L} \end{pmatrix} + \begin{pmatrix} e_{1t} \\ e_{2t} \\ \vdots \\ e_{Nt} \end{pmatrix} \end{aligned} \tag{2}$$

where $e_t \sim N\left(0, \Sigma_t\right)$ and covariance is captured through the matrix:

$$\Sigma_t = \begin{pmatrix} \Sigma_{11t} & \Sigma_{12t} & \dots & \Sigma_{1Nt} \\ \Sigma_{21t} & \Sigma_{22t} & \dots & \Sigma_{2Nt} \\ \vdots & \vdots & \ddots & \vdots \\ \Sigma_{N1t} & \Sigma_{N2t} & \dots & \Sigma_{NNt} \end{pmatrix}$$

Such a specification suffers from over-parameterization due to the fact that even a small PVAR is characterized by a high parameter-space dimensionality. Working with an unrestricted PVAR, this means that $(NG)^2 L$ autoregressive coefficients and $NG(NG+1)/2$ parameters in the error covariance matrix have to be estimated. As we discuss later, in our case of $G = 5$, $N = 10$ and $L = 1$, we would have to estimate 2500 VAR parameters and 1275 error variances and covariances. Furthermore, the inference based on an unrestricted PVAR lacks solid economic interpretation. The way of overcoming this problem is by the imposition of structural restrictions. Following Canova and Ciccarelli (2013), we focus on four groups of restrictions; (i) cross-sectional homogeneities (CSH), (ii) lack of dynamic interdependencies (DI), (iii) no static interdependencies (SI) and (iv) dynamic homogeneities (DH). Each set of restrictions reflects a specific set of relationships among the examined economies. In what follows we provide a summary of these restrictions.

The first category refers to the possibility of having homogeneous coefficients across different units. Assuming that there are cross-sectional homogeneities, this means that $A^l_{ikt} = A^l_{jkt}$ and $\Sigma_{iit} = \Sigma_{jjt}$ when $i \neq j$. In the present study it would be quite unrealistic to assume homogeneity amongst the examined economies. Despite the fact that these economies share some common characteristics, each one has a different structure with distinctive features and history. Therefore we do not impose this kind of restrictions and we let cross-sectional heterogeneities, i.e., $A^l_{ikt} \neq A^l_{jkt}$ and $\Sigma_{iit} \neq \Sigma_{jjt}$ when $i \neq j$. Computationally, this is equivalent to computing a domestic VAR for each country.

The second type of potential restrictions are related to the lagged coefficients of each unit. More specifically, assuming lack of dynamic interdependencies is equivalent to not letting the endogenous variables of each country depend on the lags of the endogenous variables of every other country, $A^l_{ijt} = 0$ when $i \neq j$. Given the increasingly strong links across the examined economies, we allow the endogenous variables for each country to depend on the lags of the endogenous variables of every other country. In other words, due to our interest in grasping all the potential cross-sectional linkages among the examined economies, we decide not to impose this kind of restriction. Using the above notation, this is equivalent of letting $A^l_{ijt} \neq 0$ when $i \neq j$.

The lack of static interdependencies is related to the variance–covariance matrix. Mathematically, $\Sigma_{ijt} = 0$ when $i \neq j$. Given our focus on how a Chinese export shock affects other economies, and not only China, we assume static interdependencies. This means that we allow a shock in one unit to be transmitted to another unit; $\Sigma_{ijt} \neq 0$ when $i \neq j$. Even though it seems quite realistic to make these assumptions for such a panel structure, we formally test whether the above three sets are empirically valid in the next subsection.

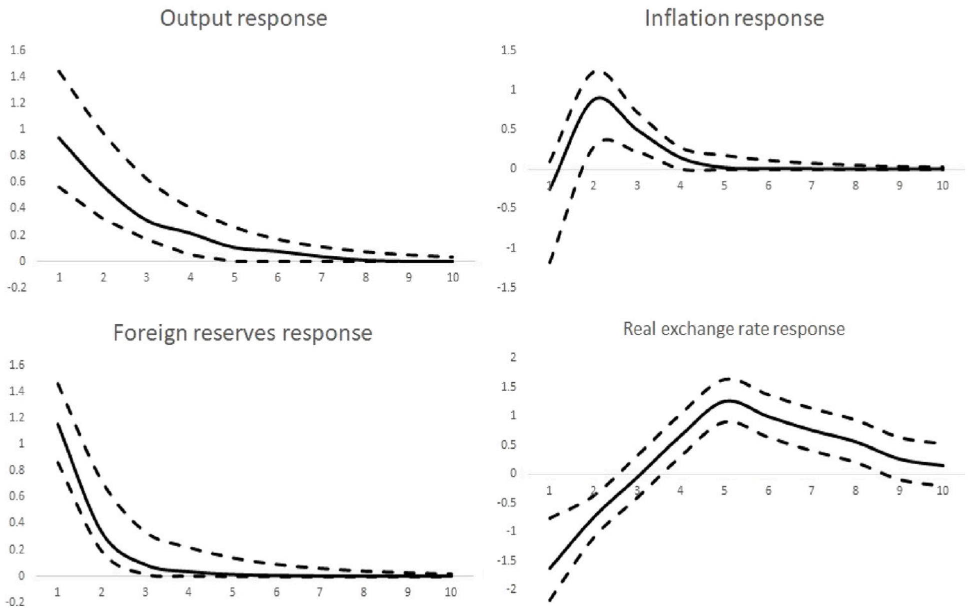


**Fig. 1.** Chinese responses to a Chinese export shock. *Notes*: The solid line depicts the responses to 1% Chinese export shock, while the dashed lines show the probability density intervals intervals.

Finally, dynamic homogeneity allows $A^l_{ijt} = A^l_{ijs}$ and $\Sigma_{ijt} = \Sigma_{ijs}$ when $s \neq t$ with $t, s \in \{1, \ldots, T\}$. Given the relatively short period of our analysis time-span, it seems reasonable to assume homoskedasticity (dynamic homogeneity). Hence, this set of restrictions is imposed within our PVAR. Even though the dimensionality is still high, the advantage of this specification is that it allows for direct dynamic interactions among countries. In this way, our model differs from single VARs that are estimated using either data from one country or panel data (pooled estimates). We estimate our model following the methodology developed by Canova and Ciccarelli (2009, 2013). The technical details are described in Appendix C in the supplementary material. One question is whether the above described structure is a realistic one. In the next subsection we present a testing procedure regarding the validity of the restrictions that we have imposed in the panel VAR.

As the focus of this study is on the cross-border spillovers stemming from China to its most important Asian partners, we include in our dataset the ASEAN-6 (Indonesia, Malaysia, Philippines, Thailand, Singapore and Vietnam). We also add to our analysis India, Japan and South Korea due to their importance on the global stage and the significant economic ties among these economies. For computational purposes, we assume one lag. Stacking over the $N$ units, the model is compactly written as:

$$y_t = A^1_t y_{t-1} + z_t + e_t, \tag{3}$$

with $y_t = (x_t, ex_t, \pi_t, xr_t, f_t)$, where $y_t$ is the vector of endogenous variables which is composed of the five variables; demeaned log real GDP ($x_t$), demeaned log exports ($ex_t$), CPI inflation rate ($\pi_t$), the real exchange rate ($xr_t$) and the demeaned log of total amount of reserves ($f_t$) for the period 1999q1-2018q4. The data are collected from Datastream. Using a battery of panel unit root tests, all the series are found to be stationary. We also add an exogenous variable, $z_t$, using the St. Louis FED financial stress index as a proxy for the global financial conditions. This ordering does not differ from the basic ordering that is frequently used in the vast empirical macroeconomic literature using VAR analysis. According to it, the macroeconomic aggregates react with a delay and not contemporaneously. Therefore, we place the real GDP and the exports as first and second variables, respectively. Typically, the inflation follows as a third variable and finally, the variables capturing financial features are usually placed at the end. We also tried alternative orderings and the results were quantitatively and quantitatively very similar.

Fig. 1 plots the responses of output, inflation, foreign reserves and real exchange rates of a 1% shock in export for China. Beginning with the economic activity, a positive export shock causes a 1% increase in the Chinese output. This is in accordance with our expectations. The same shock increases the inflation. However, this change does not take place directly, as it takes two quarters for the inflation to reach its maximum. Foreign reserves are also increased immediately with the export shock. Finally, as far as the real exchange rate is concerned, the initial effect is a small decrease. After a period of four quarters the real exchange rate increases and then gradually dies out.

Following Canova and Ciccarelli (2013), we firstly present the average responses of the remaining examined economies to a 1% Chinese export shock in Fig. 2, where we observe a similar pattern. In all examined countries we find positive output and inflation spillovers. The response of output is consistent with other studies that are based on a different empirical framework but they do take into account the international spillovers (Bi & Xin, 2021). Figs. 3 and 4 present the individual country responses of output on impact and four quarters after the shock. Interestingly, the output response is bigger for India, Vietnam, Philippines, Singapore and

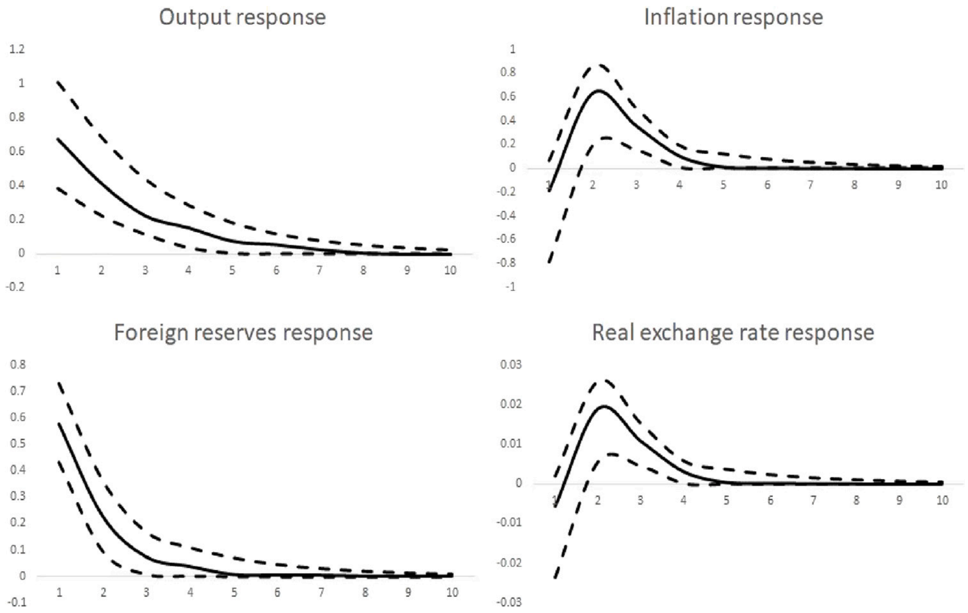


**Fig. 2.** Average ASEAN responses to a Chinese export shock. *Notes*: The solid line depicts the average responses to 1% Chinese export shock, while the dashed lines show the probability density intervals.

Indonesia. Among our examined economies, these are the countries with which China retains the largest trade surplus. The positive effects are reduced after four quarters, but for these economies they still remain statistically significant. Like for the Chinese case, the positive output boost is accompanied by an inflation increase that reaches its maximum two to three quarters after the shock.[5] The same pattern is observed for the case of foreign reserves; an increase on impact followed by a smooth decline. Finally, the real exchange rate increases more quickly for the case of trade partners. Its maximum peak is reached after two quarters and then is reduced more quickly than the Chinese rate. After five quarters it has died out.

Table 1 reports the variance decomposition. As expected, the maximum contribution of the shock to Chinese exports is related to Chinese variables, with the maximum being 45% for its output. However, the significance of the shock is important to other Asian economies, ranging from 40% in the case of India to 23% for Korea. Once more, we confirm the evidence that the effect is stronger for those economies with which China retains a strong trade surplus. After four quarters the contribution of the shock is reduced by almost half.[6]

### *2.2. Testing the validity of PVAR restrictions*

The above results were based on a structural PVAR with certain assumptions. The next step is to test whether it is reasonable to assume such a structure. Given that there is no standard testing procedure regarding the validity of these restrictions, we employ the Stochastic Search Specification Selection ($S^4$) proposed and developed by Koop and Korobilis (2016). The $S^4$ algorithm is an extension of the SSVS (Stochastic Search Variable Selection) developed by George and McCulloch (1993) for regression analysis and further extended by George et al. (2008) for VARs. The underlying assumption is that there is a prior uncertainty whose parameters (or block of parameters in our PVAR case) are insignificant and therefore can be omitted from the estimation process. For the case of PVAR this is important for two reasons. Firstly, any prior knowledge would reduce the computational burden due to the already large number of parameters. Secondly, PVAR allows us to test whether certain types of restrictions are valid or not. All the variants of the Stochastic Search Selection method assume a hierarchical prior through which it is possible to examine which parameters are most likely to be included or excluded from the model. This exercise allows us to identify which restrictions are valid to be imposed and which are not. In this way, the outcome of this procedure provides us with the chance to evaluate the assumptions imposed on our PVAR.

In our case, we have N = 10 examined countries, G = 5 dependent variables and we impose 1 lag (L = 1) using$T = 80$ observations per country. Tables 2–4 report the results for the DI, SI and CHS restrictions. Starting with the DI, the maximum amount of such inter-linkages is $N(N-1) = 90$. The DIs may go from country X to country Y but not necessarily in the reverse direction. Table 2 provides the pairs for which these linkages exist. For instance, the first entry shows that lagged Indian variables appear in the

[5] To save space and enhance readability, we report only the most salient results. All the results are available upon request.

[6] The results are remain qualitatively and quantitative the same when we repeat the same analysis for the subperiod 1999:1-2016q3 in order to examine whether the main results are driven by the global trade tensions that started around 2018. We thank an anonymous referee for this point.

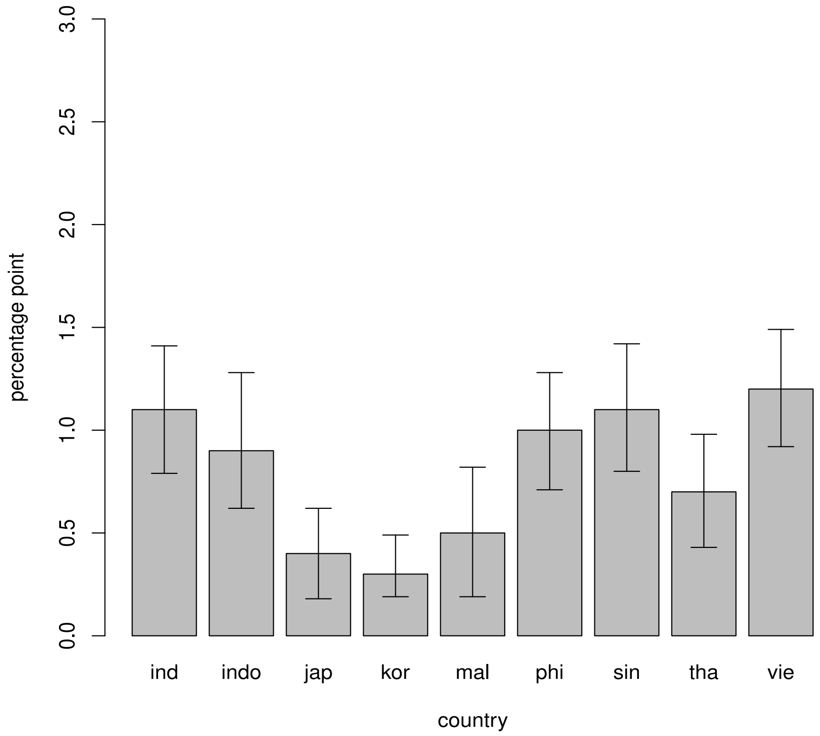


**Fig. 3.** Individual output responses to a Chinese export shock on impact. *Notes*: Bar heights indicate the responses on impact from 1% Chinese export shock, while the whiskers denote the probability density intervals. Country codes are used as follows: ind = India, indo = Indonesia, kor = Korea, mal = Malaysia, phi = Philippines, sin = Singapore, tha = Thailand, vie = Vietnam.

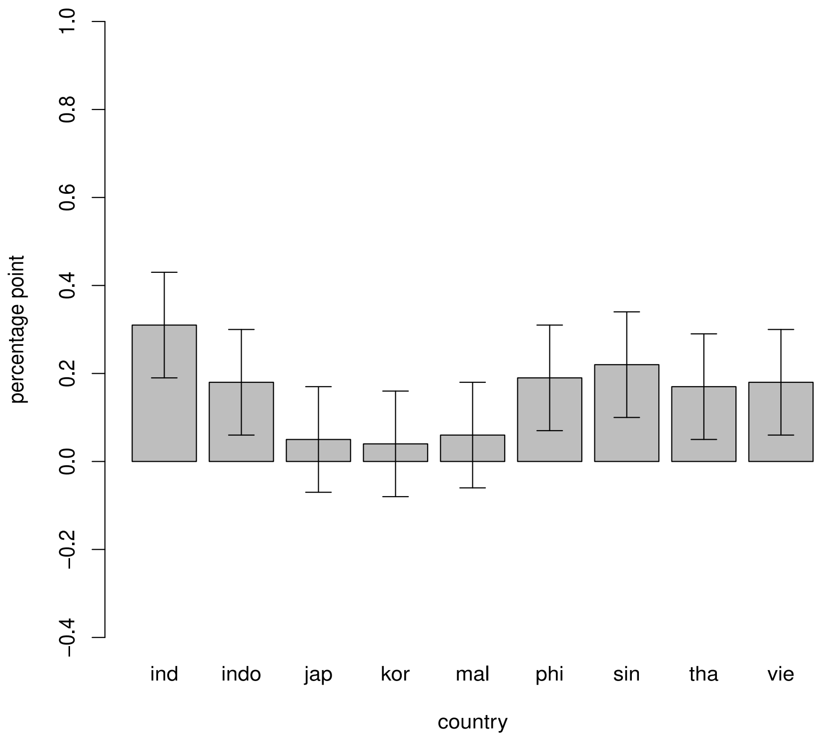


**Fig. 4.** Individual output responses to a Chinese export shock after 4 quarters. *Notes*: Bar heights indicate the responses after 4 quarters from 1% Chinese export shock, while the whiskers denote the probability density intervals. Country codes are used as follows: ind = India, indo = Indonesia, kor = Korea, mal = Malaysia, phi = Philippines, sin = Singapore, tha = Thailand, vie = Vietnam.

**Table 1**
Variance decomposition.

| Variable | 1 quarter | 4 quarters | Variable | 1 quarter | 4 quarters |
|---|---|---|---|---|---|
| Output-China | 0.45 | 0.22 | Inflation-China | 0.20 | 0.10 |
| Output-India | 0.40 | 0.22 | Inflation-India | 0.15 | 0.05 |
| Output-Indonesia | 0.30 | 0.18 | Inflation-Indonesia | 0.14 | 0.07 |
| Output-Korea | 0.23 | 0.09 | Inflation-Korea | 0.13 | 0.01 |
| Output-Japan | 0.25 | 0.10 | Inflation-Japan | 0.12 | 0.02 |
| Output-Malaysia | 0.27 | 0.12 | Inflation-Malaysia | 0.10 | 0.01 |
| Output-Philippines | 0.35 | 0.20 | Inflation-Philippines | 0.16 | 0.04 |
| Output-Singapore | 0.33 | 0.21 | Inflation-Singapore | 0.15 | 0.05 |
| Output-Thailand | 0.28 | 0.13 | Inflation-Thailand | 0.16 | 0.06 |
| Output-Vietnam | 0.34 | 0.28 | Inflation-Vietnam | 0.18 | 0.09 |
| Foreign reserves-China | 0.33 | 0.15 | Real XR-China | 0.42 | 0.23 |
| Foreign reserves-India | 0.30 | 0.14 | Real XR-India | 0.39 | 0.22 |
| Foreign reserves-Indonesia | 0.23 | 0.10 | Real XR-Indonesia | 0.33 | 0.20 |
| Foreign reserves-Korea | 0.13 | 0.07 | Real XR-Korea | 0.30 | 0.18 |
| Foreign reserves-Japan | 0.15 | 0.06 | Real XR-Japan | 0.31 | 0.18 |
| Foreign reserves-Malaysia | 0.19 | 0.09 | Real XR-Malaysia | 0.32 | 0.19 |
| Foreign reserves-Philippines | 0.25 | 0.14 | Real XR-Philippines | 0.35 | 0.19 |
| Foreign reserves-Singapore | 0.23 | 0.12 | Real XR-Singapore | 0.34 | 0.20 |
| Foreign reserves-Thailand | 0.21 | 0.10 | Real XR-Thailand | 0.32 | 0.18 |
| Foreign reserves-Vietnam | 0.28 | 0.12 | Real XR-Vietnam | 0.39 | 0.21 |

*Notes*: The entries show the forecast error variance of a specified variable at 1 and 4-quarter horizon that is attributable to 1% shock in Chinese export shock. XR denotes exchange rate.

**Table 2**
Country pairings where dynamic interdependency (DI) restrictions do not hold.

| No | To | From | No | To | From | No | To | From |
|---|---|---|---|---|---|---|---|---|
| 1 | China | India | 26 | Korea | Malaysia | 51 | Singapore | Indonesia |
| 2 | China | Indonesia | 27 | Korea | Philippines | 52 | Singapore | Japan |
| 3 | China | Japan | 28 | Korea | Singapore | 53 | Singapore | Korea |
| 4 | China | Philippines | 29 | Korea | Thailand | 54 | Singapore | Malaysia |
| 5 | China | Thailand | 30 | Korea | Vietnam | 55 | Singapore | Philippines |
| 6 | China | Vietnam | 31 | Malaysia | China | 56 | Singapore | Thailand |
| 7 | India | China | 32 | Malaysia | India | 57 | Singapore | Vietnam |
| 8 | India | Indonesia | 33 | Malaysia | Indonesia | 58 | Thailand | China |
| 9 | India | Japan | 34 | Malaysia | Japan | 59 | Thailand | India |
| 10 | India | Thailand | 35 | Malaysia | Korea | 60 | Thailand | Indonesia |
| 11 | India | Vietnam | 36 | Malaysia | Philippines | 61 | Thailand | Japan |
| 12 | Indonesia | China | 37 | Malaysia | Singapore | 62 | Thailand | Malaysia |
| 13 | Indonesia | India | 38 | Malaysia | Thailand | 63 | Thailand | Philippines |
| 14 | Indonesia | Japan | 39 | Malaysia | Vietnam | 64 | Thailand | Singapore |
| 15 | Indonesia | Thailand | 40 | Philippines | China | 65 | Thailand | Vietnam |
| 16 | Indonesia | Vietnam | 41 | Philippines | India | 66 | Vietnam | China |
| 17 | Japan | China | 42 | Philippines | Indonesia | 67 | Vietnam | India |
| 18 | Japan | Korea | 43 | Philippines | Japan | 68 | Vietnam | Indonesia |
| 19 | Japan | Indonesia | 44 | Philippines | Korea | 69 | Vietnam | Japan |
| 20 | Japan | Thailand | 45 | Philippines | Malaysia | 70 | Vietnam | Korea |
| 21 | Japan | Vietnam | 46 | Philippines | Singapore | 71 | Vietnam | Malaysia |
| 22 | Korea | China | 47 | Philippines | Thailand | 72 | Vietnam | Philippines |
| 23 | Korea | India | 48 | Philippines | Vietnam | 73 | Vietnam | Singapore |
| 24 | Korea | Indonesia | 49 | Singapore | China | 74 | Vietnam | Thailand |
| 25 | Korea | Japan | 50 | Singapore | India | | | |

*Notes*: The entries show the pairs of countries for which the dynamic interdependencies hold.

block-VAR for China. At the same time, the reverse is also true as the 7th entry shows; Chinese lagged variables are affecting the Indian part. Overall, 74 out of 90 DI, i.e., more than 80% are valid. This means that the majority of the restrictions do not hold. In this way, it is a legitimate strategy to assume the existence of dynamic interdependencies. Interestingly, China seems to be quite interconnected; Chinese variables seem to appear in the block-VARs of all the remaining countries. China appears in the column "from" for all the nine combinations (with the remaining nine countries). This means that the coefficients of Chinese variables are statistically significant in each country VAR-block.

In a similar fashion, Table 3 shows the corresponding results for static interdependencies (SI). For example, the third entry shows that $\Sigma_{China,Korea} \neq 0$. Contrary to DIs, static interdependencies are symmetric. This means that there is no difference between, let us say, $\Sigma_{China,Korea}$ and $\Sigma_{Korea,China}$ as they are the same G*G covariance block. With a maximum amount of $N(N-1)/2 = 45$, the $S^4$ procedure finds that 40 combinations of SI exist. This corresponds to more than 90% of the sample, which is composed

**Table 3**
Country pairings where static interdependency (SI) restrictions do not hold.

| No | C1 | C2 | No | C1 | C2 | No | C1 | C2 |
|---|---|---|---|---|---|---|---|---|
| 1 | China | India | 16 | India | Thailand | 31 | Korea | Thailand |
| 2 | China | Indonesia | 17 | Indonesia | Japan | 32 | Malaysia | Philippines |
| 3 | China | Korea | 18 | Indonesia | Malaysia | 33 | Malaysia | Singapore |
| 4 | China | Japan | 19 | Indonesia | Philippines | 34 | Malaysia | Thailand |
| 5 | China | Malaysia | 20 | Indonesia | Singapore | 35 | Malaysia | Vietnam |
| 6 | China | Philippines | 21 | Indonesia | Thailand | 36 | Philippines | Singapore |
| 7 | China | Singapore | 22 | Indonesia | Vietnam | 37 | Philippines | Thailand |
| 8 | China | Thailand | 23 | Japan | Korea | 38 | Philippines | Vietnam |
| 9 | China | Vietnam | 24 | Japan | Malaysia | 39 | Singapore | Thailand |
| 10 | India | Indonesia | 25 | Japan | Philippines | 40 | Singapore | Vietnam |
| 11 | India | Japan | 26 | Japan | Singapore | | | |
| 12 | India | Korea | 27 | Japan | Vietnam | | | |
| 13 | India | Malaysia | 28 | Korea | Malaysia | | | |
| 14 | India | Philippines | 29 | Korea | Philippines | | | |
| 15 | India | Singapore | 30 | Korea | Singapore | | | |

*Notes*: The entries show the pairs of countries for which the static interdependencies hold.

**Table 4**
Country pairings where cross-sectional homogeneity (CS) restrictions do not hold.

| No | C1 | C2 | No | C1 | C2 | No | C1 | C2 |
|---|---|---|---|---|---|---|---|---|
| 1 | China | India | 16 | India | Thailand | 31 | Korea | Singapore |
| 2 | China | Indonesia | 17 | India | Vietnam | 32 | Korea | Thailand |
| 3 | China | Korea | 18 | Indonesia | Japan | 33 | Korea | Vietnam |
| 4 | China | Japan | 19 | Indonesia | Malaysia | 34 | Malaysia | Philippines |
| 5 | China | Malaysia | 20 | Indonesia | Philippines | 35 | Malaysia | Thailand |
| 6 | China | Philippines | 21 | Indonesia | Singapore | 36 | Malaysia | Vietnam |
| 7 | China | Singapore | 22 | Indonesia | Thailand | 37 | Philippines | Singapore |
| 8 | China | Thailand | 23 | Indonesia | Vietnam | 38 | Singapore | Thailand |
| 9 | China | Vietnam | 24 | Japan | Korea | 39 | Singapore | Vietnam |
| 10 | India | Indonesia | 25 | Japan | Malaysia | | | |
| 11 | India | Japan | 26 | Japan | Philippines | | | |
| 12 | India | Korea | 27 | Japan | Singapore | | | |
| 13 | India | Malaysia | 28 | Japan | Vietnam | | | |
| 14 | India | Philippines | 29 | Korea | Malaysia | | | |
| 15 | India | Singapore | 30 | Korea | Philippines | | | |

*Notes*: The entries show the pairs of countries for which the cross-sectional heterogeneities hold.

of countries that are interlinked through the error covariance matrix. We interpret this finding as evidence in favour of assuming static interdependencies among the examined countries. Once more China is interconnected with all the remaining economies; its covariance matrix with all the remaining economies has no elements equal to zero. Finally, Table 4 reports the outcome for the $N(N-1)/2 = 45$ cross-sectional heterogeneities. For example, the fourth entry shows that the assumption of homogeneity between China and Japan is rejected; $A_{China} \neq A_{Japan}$. Like in the case of SIs, the CSHs are also symmetric. According to the results, 87% (39 out of 45) of the combinations reject the assumption of homogeneity. As in the previous two cases, we interpret this evidence as a validation for our earlier choice to assume that each country VAR-block is different from the others.

## 3. The model

We develop a two-country DSGE model with trade links between a home country (i.e. China) and a foreign country (i.e. an Asia Pacific country). In the model, we view the Asia Pacific countries as a consolidate entity. Following a typical structure in the two-country DSGE literature (e.g., Bhattarai et al. (2021), Mumtaz and Theodoridis (2017) and Poutineau and Vermandel (2015)), we assume that the two countries share the same structure; there are the same preference and technology structures in both the home and the foreign countries.

We use super script $h$ to denote the home country, $f$ to denote the foreign country, and $*$ to denote the international market. For parsimony the following exposition focuses on the home country. Sections 3.1 to 3.5 present key components of the model and Sections 3.6 to 3.8 present simulation results based on the model.

### 3.1. Households

Following Chang et al. (2015), the representative household derives utility from consumption $C_t$, real cash holding $M_t/P_t$ and leisure. The household holds both domestic bonds $B_t$ and international bonds $B_t^*$ and it maximizes the expected lifetime utility:

$$\max E_t \sum_{l=0}^{\infty} \beta^l [log(C_{t+l}) + \psi_m log(\frac{M_{t+l}}{P_{t+l}}) - \frac{\psi_l (L_{t+l})^{1+\eta}}{1+\eta}] \tag{4}$$

subject to the budget constraint

$$P_t C_t + M_t + (B_t + e_t B_{p,t}^*)[1 + \frac{\Omega_b}{2}(\frac{B_t}{B_t + e_t B_{p,t}^*} - \overline{\psi})] = M_{t+1} + R_{t-1} B_{t-1} + e_t R_{t-1}^* B_{p,t-1}^* + W_t L_t + D_t \tag{5}$$

where $e_t$ denotes the exchange rate, $L_t$ the labour hours, $W_t$ the wage rate, $P_t$ the price level, $R_t$ and $R_t^*$ domestic and international interest rates respectively, and $D_t$ profits from the ownership of firms; $\eta$ measures the elasticity of labour supply with respect to the wage and $\Omega_b$ measures the cost of adjusting the asset portfolio. The international interest rate $R_t^*$ is exogenous, following an AR(1) process.

### 3.2. Final goods producers

There is a continuum of monopolistic competitive final goods producers, producing a differentiated product $Y_{jt}$ using labour and intermediate goods $\Gamma_{jt}$.

$$Y_{jt} = A_t \Gamma_{jt}^{\phi} L_{jt}^{1-\phi}, \ \phi \in (0,1) \tag{6}$$

where $A_t$ is a TFP shock following an AR(1) process and $\phi$ is the share of the intermediate goods. Following Rotemberg (1982), final goods producers face a quadratic price adjustment cost $\frac{\Omega_p}{2}(\frac{P_{jt}}{\pi P_{jt-1}} - 1)^2 Y_t$ where $\Omega_p$ is the magnitude of the cost and $\pi$ is the steady-state inflation.

The cost minimization yields relative demand between the two inputs, i.e. labour hours and intermediate goods. The expected profit maximization yields the optimal price level.

### 3.3. Intermediate goods producers

Intermediate goods producers use domestically produced final goods $\Gamma_t^{h,h}$ and imported final goods $\Gamma_t^{h,im}$ to produce intermediate goods $\Gamma_t^h$.

$$\Gamma_t^h = (\Gamma_t^{h,h})^{\alpha} (\Gamma_t^{h,im})^{1-\alpha}, \ \alpha \in (0,1) \tag{7}$$

where $\alpha$ is the expenditure share of domestic input. The intermediate goods producers minimize cost to yield the relative price of intermediate goods.

### 3.4. International trade and current account

The home country imports intermediate goods (e.g. materials) from the foreign country. The foreign demand is given by

$$X_t = q_t^{\theta} \Gamma_t^{f,im} X_t^* \tag{8}$$

where $q_t = e_t P_t^*/P_t$ is the real exchange rate. Eq. (8) shows that the export $X_t$ of the home country has three components, including an exchange rate pass-through term $q_t^{\theta}$, import demand from the foreign country $\Gamma_t^{f,im}$, and an exogenous demand from the international market. The exogenous demand is captured by a home-specific export shock $X_t^*$, which follows an AR(1) process.[7] Compared with Chang et al. (2015), we augment their foreign demand with the import from the foreign country. This extra term captures a direct trade link between the home country and the foreign country. Since we isolate this trade activity from $X_t^*$, the latter variable is interpreted as foreign demand from non-ASEAN countries, such as that from the EU and the US.

The current account balance equals the sum of trade surplus and net interest income received from holdings of foreign assets.

$$CA_t = X_t - q_t \Gamma_t^{h,im} + \frac{e_t (R_{t-1}^* - 1) B_{t-1}^*}{P_t} \tag{9}$$

Since a current-account surplus (deficit) implies increases (decreases) in the country's holdings of foreign bonds, the evolution of foreign bonds is given by

$$CA_t = e_t \frac{B_t^* - B_{t-1}^*}{P_t} \tag{10}$$

[7] Since $X_t^*$ is a specific shock for the home country, it would not directly affect the foreign country.

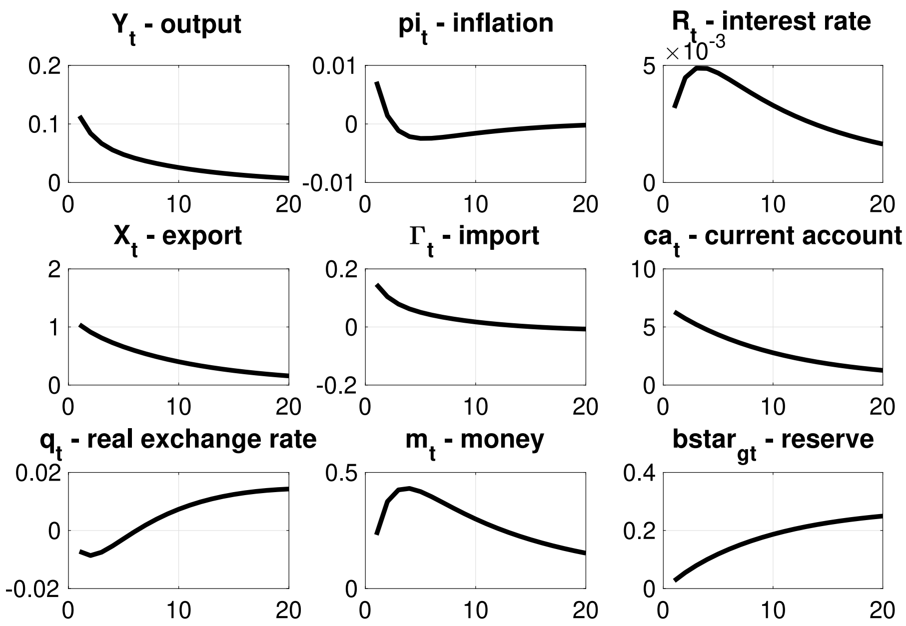


**Fig. 5.** IRFs to the export shock: the home. *Notes*: This figure shows impulse responses for the home country to the expansionary export shock. Variables are expressed as percentage deviations from the trend.

### 3.5. Equilibrium and monetary policies

The resource constraint and GDP are given by

$$Y_t = C_t + \Gamma_t^h + X_t + \frac{\Omega_p}{2}(\frac{\pi_t}{\pi} - 1)^2 Y_t + \frac{B_t + e_t B_{p,t}^*}{P_t}(\psi_t - \overline{\psi}) \tag{11}$$

$$GDP_t = C_t + X_t - q_t \Gamma_t^{h,im} \tag{12}$$

In equilibrium, markets for final and intermediate goods, labour, bonds, and money are all clear.

The central bank purchases foreign assets from firms as foreign reserves. To finance this purchase, the central bank issues domestic bonds and money.

$$e_t(B_{g,t}^* - R_{t-1}^* B_{g,t-1}^*) \leqslant B_{g,t} - R_{t-1} B_{g,t-1} + M_t - M_{t-1} \tag{13}$$

where $B_{g,t}^*$ is the foreign bonds held by the home central bank.

Finally, we complete the model by adding the interest rate determination using a Taylor-type rule.[8]

$$R_t = R_{t-1}^{\rho_r}[R(\frac{\pi_t}{\overline{\pi}})^{\rho_\pi}(\frac{Y_t}{Y_{t-1}})^{\rho_y}]^{1-\rho_r}\varepsilon_t^m \tag{14}$$

### 3.6. The export shock and spillover effects

In this subsection, we present theoretical results based on simulation of the DSGE model.[9] In particular, we show the impulse response to the home export shock which provides a theoretical interpretation of our empirical evidence as shown in Section 2.1.

Fig. 5 shows impulse responses to a positive export shock for the home country. An increase in the export boosts aggregate demand, increasing output and inflation. Consequently, the central bank raises its interest rate. Meanwhile, the export shock increases the current account balance and the accumulation of foreign reserve. To finance the purchase of foreign assets, the central bank expands its money supply. Moreover, increased home production also stimulates the demand for imported goods, generating a spillover effect on the foreign country which we illustrate using Fig. 6.

Fig. 5 also shows an interesting overshooting pattern of real exchange rate which first appreciates followed by depreciation. Such a pattern is consistent with our results from panel VAR analysis. Given the fixed exchange rate regime, an increase in the inflation leads to the initial appreciation of the exchange rate. However, as the demand for import goods rises, the price of imported goods goes up. This further pushes up real exchange rate (given the fixed exchange rate regime) in the later periods, leading to an overshooting pattern.

[8] A full set of equilibrium conditions is shown in Appendix A in the supplementary material.

[9] Calibration is shown in Appendix B in the supplementary material.

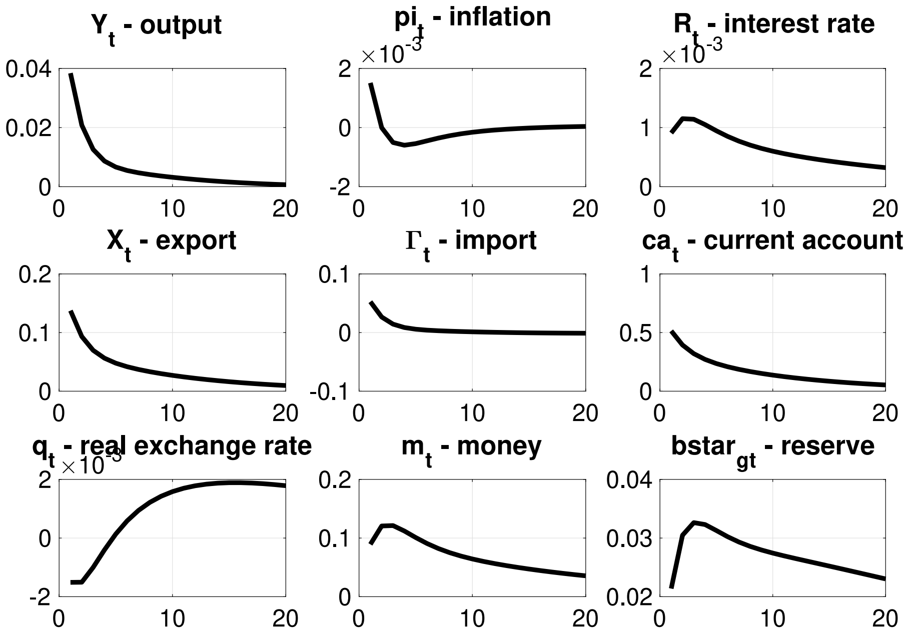


**Fig. 6.** IRFs to the export shock: the foreign. *Notes*: This figure shows impulse responses for the foreign country to the expansionary export shock. Variables are expressed as percentage deviations from the trend.

Next we illustrate how the export shock hitting the home country is transmitted to the foreign country using Fig. 6. Following the increased demand for imported goods in the home country, the export in the foreign country is stimulated. This generates similar effects as in the home country, boosting aggregate demand. Consequently, there are increases in output, inflation, current account balance and foreign reserves in the foreign country. Comparing the two countries, the direction of movement for both home and foreign variables are the same. However, impulse responses for the variables in the foreign country are less persistent with smaller magnitude. These two features are consistent with our findings based on the panel VAR.

### 3.7. *Openness and heterogeneity of the spillover effects*

The empirical results in Section 2.1 suggest significant variations in the spillover effects across countries. When China has large trade surplus (small surplus or even deficit) with a trade partner, the spillover effects tend to be larger (smaller). In this subsection, we provide explanations for this heterogeneous pattern through the lens of the model. To this end, we simulate the model with alternative degrees of trade openness for the home and the foreign. Specifically, we first investigate the spillover effects when there is larger export or import for the home country (see Fig. 7). Then, we further consider larger export or import for the foreign country (see Fig. 8), and compare the spillover effects in these cases with the benchmark results. At the end of this subsection, we provide connections between the empirical evidence and the theoretical findings.

Fig. 7 displays spillover effects on some foreign variables with different degrees of openness for the home (case 1). Starting with a larger export share for the home[10] implies that the export contributes more to the home aggregate demand than in the benchmark case. Comparatively, the export shock generates a larger stimulation effect on the aggregate demand, leading to a more pronounced increase in domestic production. Hence the demand for foreign goods also increases more. As a result, the home country imports more, leading to amplified spillover effects on the foreign country.

Regarding the second case, with a larger import share for the home[11] (case 2), the net export accounts for a smaller share of GDP, implying that the external demand becomes a smaller component in determining the home demand. Effects of the export shock are more likely to be absorbed by the domestic market. Consequently, the increase of home import is lower than in the benchmark case and the spillover effects are relatively dampened (see red lines in Fig. 7).

We further investigate how the degree of openness for the foreign country affects the spillover effect. Fig. 8 displays spillover effects on some foreign variables with different degrees of openness for the foreign. We first consider that the export share for the foreign is 10% higher than the benchmark value (case 3), implying that the export contributes more to the foreign aggregate

[10] The export-to-GDP ratio for the home is 10% higher than the benchmark value.

[11] We do so by increasing the imported input share 1-$\alpha$ for the home. The import-to-GDP ratio for the home is 10% higher than the benchmark value. This also implies that the home country has a trade deficit in the steady state.

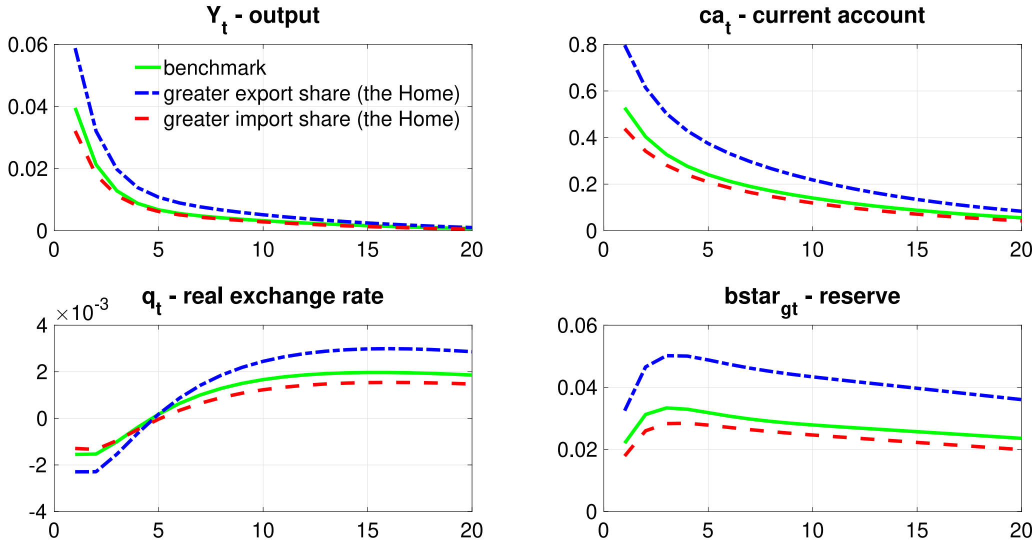


**Fig. 7.** Spillover effects: different degrees of trade links for the home. *Notes*: Figures show impulse responses of selected variables for the foreign country to an expansionary export shock. Solid green lines denote the benchmark, dash-dotted blue lines show the greater export share and the dashed red lines shows the greater import share. Variables are expressed as percentage deviations from the trend.

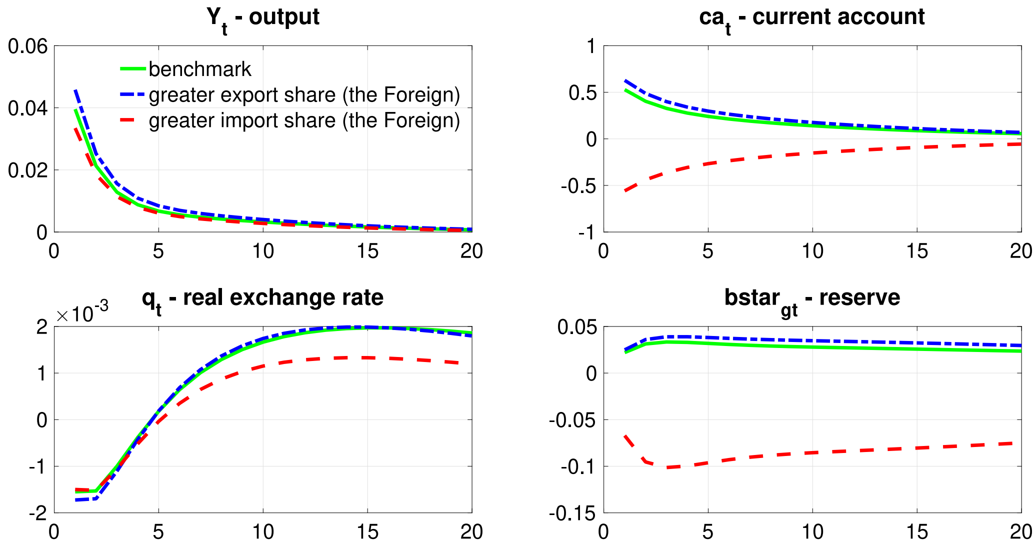


**Fig. 8.** Spillover effects: different degrees of trade links for the foreign. *Notes*: Figures show impulse responses of selected variables for the foreign country to an expansionary export shock. Variables are expressed as percentage deviations from the trend. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

demand. In such a case, the spillover effect that stimulates the foreign export can be more efficient to boost the foreign aggregate demand. Not surprisingly, we observe magnified spillover effects in this case as shown by the blue lines in Fig. 8.

Finally, we consider that the import share for the foreign[12] is 10% larger than the benchmark value (case 4). In this case, the trade position of the foreign turns from a surplus to deficit in the steady state. Fig. 8 shows that the spillover effect on the foreign output is dampened. Compared with the benchmark case, a starker difference is that the current account balance and the reserve for the foreign have negative responses. Given that the import share is larger than the export share for the foreign in this case, the spillover effect which increases the foreign import could cause deterioration in the trade deficit. As a result, the current account balance deteriorates as well, which further discourages accumulation of reserve for the foreign.

[12] We do so by increasing the imported input share 1-$\alpha$ for the foreign country.

**Table 5**
Correlations between key variables across countries.

| Correlations | Model | | Data |
|---|---|---|---|
| | Export shock (i) | All shocks (ii) | (iii) |
| $\rho(Y_t^h, Y_t^f)$ | 0.93 | 0.88 | 0.85 |
| $\rho(\pi_t^h, \pi_t^f)$ | 0.94 | 0.66 | 0.69 |
| $\rho(X_t^h, X_t^f)$ | 0.96 | 0.57 | 0.67 |
| $\rho(q_t^h, q_t^f)$ | 0.82 | −0.34 | −0.62 |
| $\rho(b_{g,t}^{*,h}, b_{g,t}^{*,f})$ | 0.74 | 0.71 | 0.54 |

*Notes*: Column (iii) lists averaged correlations for the group of Asian economies in the sample.

Overall our findings in this subsection shed light on the heterogeneity in the spillover effects of the export shock. In general, we find that the spillover effects depend on the degree of openness and trade positions. The magnitude of spillover effects tends to be large if either the home or the foreign has large trade surplus, holding others as constant, implying that export penetration amplifies the transmission of the export shock. On the contrary, import penetration could dampen the spillover effect, particularly on output. The spillover effect on current account and reserve could even be reversed if the foreign country has significant trade deficit.

Furthermore, the above experiments deliver important implications that are consistent with the empirical evidence suggested by Section 2.1. The relatively larger spillover effects, e.g. the case of India, Vietnam and Singapore, tend to be consistent with the combination of cases 1 and 3 in the theoretical analysis; these countries and China both have a large amount of trade surplus and China holds positive trade balance with them. The relatively smaller spillover effects, e.g. the case of Japan and Korea, tend to be consistent with the combination of cases 2 and 3 in the theoretical analysis; China holds a negative trade balance with Japan and Korea.

### *3.8. Business cycle comovement*

The impulse response analysis in both the empirical and theoretical parts implies cross-country comovement in some key variables. In this subsection, we further provide support for this finding using model-implied correlations.

Table 5 presents model-implied correlations for variables that are used in both the empirical and theoretical analysis (see columns (i) and (ii)). Based on column (i), Table 5 shows pronounced positive comovement patterns induced by the export shock between the home and the foreign with respect to the output, inflation, export, real exchange rate and reserves. We also calculate model-implied correlations after incorporating other shocks for the home[13], which is useful to examine the comovement pattern due to a broad set of shocks through the trade spillover channel. When the extra shocks are included in the model, the comovement patterns remain apparent, especially for the output, inflation, exports and reserves.

Finally, we compare the empirical and model-implied correlations. This experiment is useful to show to what extent the model matches the overall correlation observed in the data. We find that the model-implied correlations are close to the data counterparts (column (iii) in Table 5), indicating that the spillover effects are captured by the model. The model is thus effective to match the correlation in data even in the absence of local shocks for the foreign. In particular, the export shock is a key driver to generate the tight comovement in the output. This finding is not surprising given that the export shock explains about 30% to 40% of variation in the output for the Asian Pacific countries as shown in Table 1.

## 4. Conclusions

The current paper examines the international spillover effects of a Chinese export shock to other Asian economies. Using a panel VAR for the empirical analysis followed by a two-country DSGE model, we show that a Chinese export shock strongly affects all the examined Asian pacific countries. We demonstrate that the trade link is an important transmission mechanism and a significant component of the business cycle synchronization. The economic developments over the last years indicate that the promotion of a deeper tightening of the economies in the Asian-pacific region is an explicit target. The recent RCEP agreement is a result of this aim. The inclusion of more detailed financial characteristics of the examined economies can show further insights for the economic integration process. We leave this kind of extension for future research.

## CRediT authorship contribution statement

**Georgios Magkonis:** Conceptualization, Data curation, Methodology, Software, Formal analysis, Writing – original draft, Validation, Visualization. **Simon Rudkin:** Methodology, Software, Writing – review & editing. **Shuonan Zhang:** Conceptualization, Data curation, Methodology, Software, Formal analysis, Writing – original draft, Validation, Visualization.

[13] We include a TFP shock, a monetary policy shock, an exchange rate shock and a world interest rate shock. Note that the world interest rate shock also affects the foreign directly.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

## Appendix A. Equilibrium conditions

### Equilibrium conditions for the home country

$$\Lambda_t^h = \frac{1}{C_t^h} \tag{15}$$

$$1 = \beta E_t \frac{\Lambda_{t+1}^h}{\Lambda_t^h} \frac{R_t^h}{\pi_{t+1}^h} \tag{16}$$

$$\Lambda_t^h w_t^h = \psi (L_t^h)^\eta \tag{17}$$

$$\frac{\Psi_m}{m_t^h \Lambda_t^h} = \frac{R_t^h - 1}{R_t^h} \tag{18}$$

$$\Psi_t^h = \frac{B_t^h}{B_t^h + e_t^h B_{p,t}^{h,*}} \tag{19}$$

$$\Omega_b(\Psi_t^h - \Psi^h) = \beta E_t \frac{\Lambda_{t+1}^h}{\Lambda_t^h} \frac{1}{\pi_{t+1}^h} (R_t^h - R_t^* \frac{e_{t+1}^h}{e_t^h}) \tag{20}$$

$$\upsilon_t^h = \phi^{-\phi}(1-\phi)^{\phi-1}(q_{mt}^h)^\phi (w_t^h)^{1-\phi} \tag{21}$$

$$w_t^h = (1-\phi)\frac{\upsilon_t^h Y_t^h}{L_t^h} \tag{22}$$

$$Y_t^h = (\Gamma_t^h)^\phi (A_t^h L_t^h)^{1-\phi} \tag{23}$$

$$\upsilon_t^h = \frac{\theta_p - 1}{\theta_p} + \frac{\Omega_p^h}{\theta_p}[(\frac{\pi_t^h}{\pi} - 1)\frac{\pi_t^h}{\pi} - \beta E_t(\frac{\pi_{t+1}^h}{\pi} - 1)\frac{\pi_{t+1}^h}{\pi}] \tag{24}$$

$$\Gamma_t^h = (\Gamma_t^{h,h})^{\alpha^h} (\Gamma_t^{h,im})^{1-\alpha^h} \tag{25}$$

$$q_t^h = e_t^h \frac{P_t^*}{P_t^h} \tag{26}$$

$$\frac{q_t^h}{q_{t-1}^h} = g_{e,t}^h \frac{\pi_t^*}{\pi_t^h} \tag{27}$$

$$q_{m,t}^h = \overline{\alpha^h}(q_t^h)^{1-\alpha} \tag{28}$$

$$q_t^h = \frac{1-\alpha^h}{\alpha^h} \frac{\Gamma_t^{h,h}}{\Gamma_t^{h,im}} \tag{29}$$

$$X_t^h = (q_t^h)^\theta \Gamma_t^{f,im} X_t^* \tag{30}$$

$$ca_t^h = X_t^h - q_t^h \Gamma_t^{h,im} + \frac{e_t^h (R_{t-1}^* - 1) B_{t-1}^{h,*}}{P_t^h} \tag{31}$$

$$ca_t^h = e_t^h \frac{B_t^{h,*} - B_{t-1}^{h,*}}{P_t^h} \tag{32}$$

$$Y_t^h = C_t^h + \Gamma_t^h + X_t^h + \frac{\Omega_p^h}{2}(\frac{\pi_t^h}{\pi} - 1)^2 Y_t^h + \frac{B_t^h + e_t^h B_{p,t}^{h,*}}{P_t^h}(\psi_t^h - \overline{\psi^h}) \tag{33}$$

$$GDP_t^h = C_t^h + X_t^h - q_t^h \Gamma_t^{h,im} \tag{34}$$

$$R_t^h = (R_{t-1}^h)^{\rho_r}[R(\frac{\pi_t^h}{\overline{\pi}})^{\rho_\pi}(\frac{Y_t^h}{Y_{t-1}^h})^{\rho_y}]^{1-\rho_r}\varepsilon_t^{m,h} \tag{35}$$

$$e_t^h(B_{g,t}^{h,*} - R_t^* B_{g,t-1}^{h,*}) = B_{g,t}^h - R_t^h B_{g,t-1}^h + M_t^h - M_{t-1}^h \tag{36}$$

**Equilibrium conditions for the foreign country**

$$\Lambda_t^f = \frac{1}{C_t^f} \tag{37}$$

$$1 = \beta E_t \frac{\Lambda_{t+1}^f}{\Lambda_t^f}\frac{R_t^f}{\pi_{t+1}^f} \tag{38}$$

$$\Lambda_t^f w_t^f = \psi(L_t^f)^\eta \tag{39}$$

$$\frac{\psi_m}{m_t^f \Lambda_t^f} = \frac{R_t^f - 1}{R_t^f} \tag{40}$$

$$\Psi_t^f = \frac{B_t^f}{B_t^f + e_t^f B_{p,t}^{f,*}} \tag{41}$$

$$\Omega_b^f(\Psi_t^f - \Psi) = \beta E_t \frac{\Lambda_{t+1}^f}{\Lambda_t^f}\frac{1}{\pi_{t+1}^f}(R_t^f - R_t^* \frac{e_{t+1}^f}{e_t^f}) \tag{42}$$

$$\upsilon_t^f = \phi^{-\phi}(1-\phi)^{\phi-1}(q_{mt}^f)^\phi(w_t^f)^{1-\phi} \tag{43}$$

$$w_t^f = (1-\phi)\frac{\upsilon_t^f Y_t^f}{L_t^f} \tag{44}$$

$$Y_t^f = (\Gamma_t^f)^\phi(A_t^f L_t^f)^{1-\phi} \tag{45}$$

$$\upsilon_t = \frac{\theta_p - 1}{\theta_p} + \frac{\Omega_p^f}{\theta_p}[(\frac{\pi_t^f}{\pi} - 1)\frac{\pi_t^f}{\pi} - \beta E_t(\frac{\pi_{t+1}^f}{\pi} - 1)\frac{\pi_{t+1}^f}{\pi}] \tag{46}$$

$$\Gamma_t^f = (\Gamma_t^{f,h})^\alpha(\Gamma_t^{f,im})^{1-\alpha} \tag{47}$$

$$q_t^f = e_t^f \frac{P_t^*}{P_t^f} \tag{48}$$

$$\frac{q_t^f}{q_{t-1}^f} = g_{e,t}^f \frac{\pi_t^*}{\pi_t^f} \tag{49}$$

$$q_{m,t}^f = \overline{\alpha^f}(q_t^f)^{1-\alpha} \tag{50}$$

$$q_t^f = \frac{1-\alpha^f}{\alpha^f}\frac{\Gamma_t^{f,h}}{\Gamma_t^{f,im}} \tag{51}$$

$$X_t^f = (q_t^f)^\theta \Gamma_t^{h,im} \tag{52}$$

$$ca_t^f = X_t^f - q_t^f \Gamma_t^{f,im} + \frac{e_t^f(R_{t-1}^* - 1)B_{t-1}^{f,*}}{P_t^f} \tag{53}$$

$$ca_t^f = e_t^f \frac{B_t^{f,*} - B_{t-1}^{f,*}}{P_t^f} \tag{54}$$

$$Y_t^f = C_t^f + \Gamma_t^f + X_t^f + \frac{\Omega_p^f}{2}(\frac{\pi_t^f}{\pi} - 1)^2 Y_t^f + \frac{B_t^f + e_t^f B_{p,t}^{f,*}}{P_t^f}(\psi_t^f - \overline{\psi^f}) \tag{55}$$

$$GDP_t^f = C_t^f + X_t^f - q_t^f \Gamma_t^{f,im} \tag{56}$$

$$R_t^f = (R_{t-1}^f)^{\rho_r}[R(\frac{\pi_t^f}{\overline{\pi}})^{\rho_\pi}(\frac{Y_t^f}{Y_{t-1}^f})^{\rho_y}]^{1-\rho_r}\varepsilon_t^{m,f} \tag{57}$$

$$e_t^f(B_{g,t}^{f,*} - R_t^* B_{g,t-1}^{f,*}) = B_{g,t}^f - R_t^f B_{g,t-1}^f + M_t^f - M_{t-1}^f \tag{58}$$

**Table 6**
Calibrated parameters.

| Common parameters | Description | Value | |
|---|---|---|---|
| $\beta$ | Discount factor | 0.995 | |
| $\eta$ | Labour elasticity | 2 | |
| $\phi$ | Cost share of intermediate goods | 0.5 | |
| $\psi_m$ | Money preference | 0.02 | |
| $\theta_p$ | Elasticity of substitution | 10 | |
| $\theta$ | Export demand elasticity | 1.5 | |
| $\rho_r$ | Taylor smoothing | 0.8 | |
| $\rho_\pi$ | Taylor inflation parameter | 1.65 | |
| $\rho_y$ | Taylor output growth parameter | 0.15 | |
| $L$ | Steady state labour hour | 0.4 | |
| $R^*$ | Steady state foreign interest rate | 1.0125 | |
| Country-specific | | Home | Foreign |
| $\alpha$ | Share of domestic intermediate goods | 0.75 | 0.45 |
| $1+g^y$ | Steady state per capita GDP growth | 1.02 | 1.01 |
| $\overline{\psi}$ | Average portfolio share of domestic bonds | 0.9 | 0.75 |
| $\Omega_b^h$ | Portfolio adj. cost parameter | 0.6 | 0.27 |
| $\Omega_p$ | Price adj. cost parameter | 45 | 76 |
| $\rho_x$ | Persistence of export shock | 0.9 | \ |
| $\sigma_x$ | Standard deviation of export shock | 1 | \ |

## Appendix B. Calibration

For parameters well-identified in the literature and less variant across countries, we calibrate them using common values. For country-specific parameters, we make calibrations based on region-specific targets. The home parameters are referenced to China while the foreign counterparts are referenced to emerging Asia excluding China.

Table 6 presents calibrated parameter values including two parts. The upper panel shows values for common parameters while the lower panel shows values for country specific parameters. The columns Home and Foreign show values for home and foreign specific parameters respectively. Starting from common parameters, the subjective discount factor $\beta$ and Frisch labour supply elasticity $\eta$ are set to 0.995 and 2 which are often found in literature, e.g. Christiano et al. (2005) . Following Chang et al. (2015), the cost share of intermediate goods $\phi$ is set to 0.5. The money preference parameter $\psi_m$ is calibrated as 0.02, implying a money-to-GDP ratio of 52% which is at a moderate level for emerging Asian countries. We set the elasticity of substitution of final goods $\theta_p$ as 10, implying a final goods mark-up of 1.1. The export demand elasticity $\theta$ is calibrated as 1.5 which is consistent with the estimate based on aggregate data (see Imbs and Mejean (2015) among others). Regarding the monetary policy parameters, we set $\rho_r$, $\rho_\pi$ and $\rho_y$ as 0.8, 1.65 and 0.15 respectively in line with empirical estimates e.g. Caporale et al. (2018), Moura and de Carvalho (2010) and Zhang (2020). For the two steady states parameters, the world interest rate $R^*$ is calibrated as 1.0125 in line with Devereux et al. (2019) at the quarterly frequency, the steady state labour hour $L$ is set as 0.4.

Shifting to country-specific parameters, the share of domestic intermediate goods $\alpha$ is calibrated as 0.75 and 0.45 for the home and foreign countries respectively, matching import-to-GDP ratio data (0.2 for China and 0.45 for emerging Asia). The steady state per capita GDP growth $1 + g^y$ is set as 1.02 and 1.01, consistent with the quarterly growth rate of per capita GDP for China and emerging Asia in the last 25 years. The price adjustment parameter $\Omega_p$, is set as 45 for the home and 76 for the foreign. These values lie in the range considered in the literature (Chang et al., 2015, 2019; Devereux et al., 2019).

Turning to the average portfolio share of domestic bonds $\overline{\psi}$, we follow Chang et al. (2015) to give China a relatively higher value (0.9) than the foreign counterpart (0.75). Similarly, the portfolio adjustment cost parameter $\Omega_b$ is calibrated as 0.6 for the home and 0.27 for the foreign. The calibration results for bond portfolio parameters are consistent with the fact that emerging Asia has relatively tighter capital control than the rest of the world and China has even tighter capital control than other emerging Asian countries. Regarding the export shock parameters, the persistence and standard deviation are calibrated as 0.9 and unity respectively.

## Appendix C. Econometric model

### C1. Factor model

In this section we provide an overview of the technical details for estimating the panel VAR model. The advantage of this structural factor modelling approach is that the parameter space of the panel VAR model which is estimated is significantly reduced. Specifically, from a total number of $Nn(Nnp + m) = 2550$ coefficients, with $N(= 10)$ countries, $n(= 5)$ endogenous variables, $p(= 1)$ lags and $m(= 1)$ exogenous variables, the parameters are dropped to $(1 + N + n + (p - 1) + m) = 17$ with the factor approach. The idea is to express the parameters that need estimation as a function of a few structural factors:

$$\beta = \Psi_1\ f_1 +\ \Psi_2\ f_2 + \Psi_3\ f_3 +\ \Psi_4\ f_4 +\ \Psi_5\ f_5$$

where $\beta$ is the vector of the parameters, $f$ are the vectors containing the structural factors, where $f_1$ is a common factor, $f_2$ is the unit-specific factor that captures the components which are specific to each country, $f_3$ is the variable-specific factor that captures the components of each endogenous variable, $f_4$ is the lag-specific component, and $f_5$ is the factor that captures the exogenous variable. Finally, $\Psi$'s are the selection matrices whose entries are 0 or 1. We can rewrite the above equation in a stacked form as:

$$\beta = \Psi \mathrm{f}$$

The PVAR model of Eq. (1) in the main paper, can be written as $y_t = \widetilde{X}_t\beta + \varepsilon_t$, where $\widetilde{X_t}$ contains both the vector of lagged endogenous variables $(y_{i,t-1})$ and the exogenous variable $(x_t)$. In this way, we can rewrite the PVAR model as:

$$y_t = \widetilde{X}_t \Psi \mathrm{f} + \varepsilon_t = Z\mathrm{f} + \varepsilon_t$$

where,

$$Z = \widetilde{X}_t * \Psi$$

and

$$\varepsilon_t \sim N(0, \Sigma)$$

with

$$\Sigma = \sigma\widetilde{\Sigma} = \begin{pmatrix} \sigma\widetilde{\Sigma}_{11} & \cdots & \sigma\widetilde{\Sigma}_{1N} \\ \vdots & \ddots & \vdots \\ \sigma\widetilde{\Sigma}_{N1} & \cdots & \sigma\widetilde{\Sigma}_{NN} \end{pmatrix} = \begin{pmatrix} \Sigma_{11} & \cdots & \Sigma_{1N} \\ \vdots & \ddots & \vdots \\ \Sigma_{N1} & \cdots & \Sigma_{NN} \end{pmatrix}$$

and $\sigma$ is a scaling random variable which follows an inverse Gamma distribution;

$$\sigma \sim IG(\frac{\alpha}{2}, \frac{\delta}{2})$$

The benefits of this procedure become evident when we consider the dimensions of each factor. More precisely, the common factor $f_1$ is a scalar, and therefore, its dimension is $d_1 = 1$. $f_2$ is the country specific factor and therefore $d_2 = N = 10$. $f_3$ is the factor that is specific to each variable and thus $d_3 = n = 4$. $f_4$ is the lag-specific factor and $d_4 = p - 1 = 0$. Finally, $f_5$ is the factor related to the exogenous variable and therefore $d_5 = m = 1$.

In order to understand the benefits of this transformation, it is useful to analyse the first element of the $y_t$ vector, that is the variable $y_{11,t}$, which is now written as:

$$\begin{aligned} y_{11,t} = (&y_{11,t-1} + y_{12,t-1} + y_{13,t-1} + y_{14,t-1} + y_{21,t-1} + y_{22,t-1} + y_{23,t-1} + y_{24,t-1} \\ &+ y_{31,t-1} + y_{32,t-1} + y_{33,t-1} + y_{34,t-1} + y_{41,t-1} + \cdots + y_{102,t-1} + y_{103,t-1} + y_{104,t-1})f_{11} \\ &+ (y_{11,t-1} + y_{12,t-1} + y_{13,t-1} + y_{14,t-1})f_{21} \\ &+ (y_{11,t-1} + y_{21,t-1} + y_{31,t-1} + y_{41,t-1} + \cdots + y_{91,t-1} + y_{101,t-1})f_{31} \\ &+ (x_{1,t})f_{f1} + \epsilon_{11,t} \end{aligned} \tag{59}$$

So,

$$y_{11,t} = \Gamma_{11,t}f_{11} + \Gamma_{21,t}f_{21} + \Gamma_{31,t}f_{31} + x_{1,t}f_{51} + \varepsilon_{11,t} \tag{60}$$

*C2. Bayesian set-up*

The key objective is to find the posterior conditional distributions for $f$, $\widetilde{\Sigma}$, $\sigma$. To compute the posterior distribution, we start from the posterior joint probability which can written as:

$$\pi(f, \widetilde{\Sigma}, \sigma | y) \propto f(y|f, \widetilde{\Sigma}, \sigma)\pi(f)\pi(\widetilde{\Sigma})\pi(\sigma) \tag{61}$$

The likelihood function is given as:

$$f(y|f, \widetilde{\Sigma}, \sigma) \propto (\sigma)^{-TNn/2} \left|\widetilde{\Sigma}\right|^{-T/2} \prod_{t=1}^{T} \left\{ exp\left(-\frac{1}{2}\sigma^{-1}(y_t - \widetilde{X}_t f)\prime\widetilde{\Sigma}^{-1}(y_t - \widetilde{X}_t f)\right)\right\} \tag{62}$$

while the prior for $f$ is given as:

$$\pi(f|f_0, F_0) \propto exp\left(-\frac{1}{2}(f - f_0)\prime {F_0}^{-1}(f - f_0)\right) \tag{63}$$

where $f_0$ is set equal to 0 and $F_0$ is a diagonal matrix with large values in order to indicate a non-informative prior.

For $\widetilde{\Sigma}$ we use an uninformative prior as follows:

$$\pi(\widetilde{\Sigma}) \propto \left|\widetilde{\Sigma}\right|^{-(Nn+1)/2} \tag{64}$$

Finally, $\sigma$ follows an inverse Gamma distribution, that is:

$$\pi(\sigma) \propto \sigma^{-(\frac{a_0}{2})-1} exp\left(\frac{-\delta_0}{2\sigma}\right) \tag{65}$$

Using the Bayes rule, the joint posterior is given as:

$$f(f,\tilde{\Sigma},\sigma|y) \propto \prod_{t=1}^{T}\{\exp\left(-\frac{1}{2}\sigma^{-1}\left(y_t-\tilde{X}_t f\right)'\tilde{\Sigma}^{-1}\left(y_t-\tilde{X}_t f\right)\right)\times\exp\left(\frac{-\delta_0}{2\sigma}\right)$$
$$\times(\sigma)^{-(NnT+a_0)/2-1}\times|\tilde{\Sigma}|^{-(T+Nn+1)/2}\times\exp\left(-\frac{1}{2}\left(f-f_0\right)'F_0{}^{-1}\left(f-f_0\right)\right)\} \tag{66}$$

A Gibbs sampler algorithm is typically applied based on conditional posterior distributions that are easily derived as they are proportional to the joint posterior.

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