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International transmission of U.S. macroeconomic shocks in the USMCA region*

Transmisión internacional de los shocks macroeconómicos estadounidenses en la región del T-MEC

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ABSTRACT

We study the international transmission of U.S. real and financial shocks on the USMCA region using a global approach. The study relies on a GVAR (Global Vector Autoregressive) model and generalized impulse-response functions (GIRF). The main findings suggest that: 1) The USMCA economies are contemporaneously linked to the world economy mainly through private credit, international trade and real GDP; 2) shocks on U.S. GDP and U.S. trade flows have higher influence in Canada than in Mexico; 3) shocks on U.S. interest rates have higher influence in Mexico than in Canada; 4) the private credit and the international trade channels are the most important ones for the transmission of international macroeconomic shocks. The study relies on quarterly data for 33 countries of the period 1986:Q1-2019:Q4.

RESUMEN

Estudiamos la transmisión internacional de los shocks reales y financieros de Estados Unidos en la región del T-MEC utilizando un enfoque global. El estudio se basa en un modelo GVAR (Vector Global Auto-regresivo) y funciones generalizadas de impulso-respuesta (GIRF). Los principales hallazgos sugieren que: 1) Las economías del T-MEC están simultáneamente vinculadas a la economía mundial, principalmente a través del crédito privado, el comercio internacional y el PIB real; 2) los shocks sobre el PIB y los flujos comerciales de Estados Unidos tienen mayor influencia en Canadá que en México; 3) los shocks sobre las tasas de interés estadounidenses tienen mayor influencia en México que en Canadá; 4) el crédito privado y el comercio internacional son los más importantes canales para la transmisión de shocks macroeconómicos internacionales. El estudio se basa en datos trimestrales de 33 países del período 1986:T1-2019:T4.

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INTRODUCCIÓN

Traditionally, the interdependences of the USMCA economies have been studied in terms of their intra-regional trade. Usually, the specialized literature analyzes the relationships among the economies in terms of an open system approach. In other words, the literature does not explicitly consider the influence of other countries and regions of the world to describe such interdependences, i.e., a global approach. Indeed, the studies that analyze the transmission channels of real and financial shocks from an international perspective are relatively scarce. The absence of studies relates to the methodological limitations that exist to describe the relationships among large groups of countries.

The objective of this study is to analyze the international transmission of U.S. real and financial shocks on the USMCA region (U.S., Mexico and Canada), using a global approach. The study uses quarterly time-series for the period 1986:Q1 to 2019:Q4. The study contributes to the empirical literature in three relevant aspects: 1) It uses the GVAR (Global Vector Autoregressive) modeling technique to describe the macroeconomic interdependencies at the global level; 2) it focuses on the international transmission of shocks in the USMCA region to real and financial shocks originating in the United States; 3) it analyses the relevance of different channels of shocks transmission in the USMCA region.

The methodology of the study relies on statistical analyses, the estimation of a GVAR model, and the calculation of generalized impulse-response functions. Here the statistical analyses allow us to describe the series, to define their order of integration, their range of cointegration, and the existence of structural changes. The GVAR model allow us to estimate the intensity of international macroeconomic interdependencies from a global perspective. We follow the modeling approach with a dominant unit proposed by Chudik and Pesaran (2013) for analytical purposes. Finally, the impulse-response functions allow us to study the international transmission channels of real and financial shocks from the U.S. economy.

This study contributes to the literature on the international transmission of macroeconomic shocks in North America. The econometric contributions relate to the estimation of a GVAR model and the simulation of generalized impulse-response functions (GIRF). The GVAR model allows to model the macroeconomic interdependencies among the countries with coherence and consistency. Moreover, the GVAR model enable us to capture the intensity of economic relations between countries, taking into account the magnitudes of bilateral trade flows. However, unlike traditional vector autoregressive (VAR) models, this approach does not incur in degree-of-freedom problems.

The main analytical contribution consists of extending the research on the USMCA region interdependencies and the transmission of shocks. Studies that analyze these issues for the North American economies are scarce. Moreover, they usually do not consider the influence of countries outside the region. Notable exceptions among these studies are those of Bayoumi and Swiston (2008), Pentecôte and Rondeau (2015), Wei and Lahiri (2019), and Khan (2020). Here, we focus on the vulnerability of Mexico and Canada to U.S. real and financial shocks from a global perspective. The main findings suggest that trade and private credit are the most important channels for international transmission of shocks.

This paper is organized into fourth sections. The first section reviews the literature of the international transmission channels of macroeconomic shocks in the USMCA region. The second section focuses on the methodological issues. The third section shows the database and the statistical analyses. The fourth section shows the econometric estimations and the GIRF simulations of the real and financial shocks from U.S. to the economies of Mexico and Canada. At the last summarizes the conclusions and outlines lines for future research.

I. LITERATURE REVIEW

The literature of the transmission of macroeconomic shocks focuses on several channels that explain the interdependences and vulnerabilities among the economies. Indeed, some studies suggest that trade linkages are the most important channels for the transmission of shocks across countries (Imbs, 2004; Baxter and Kouparitsas, 2005; Haile and Pozo, 2008; Lee, *et al*., 2011). However, other studies suggest that shocks can be transmitted through multiple channels in addition to the trade linkages (Leila, 2011; Sevinc and

Mata-Flores, 2021). These complementary channels relate to the synchronization of business cycles, The behavior of international financial markets and central banks' monetary policy.

The literature on the international propagation channels of shocks using the business cycle synchronization approach shows that international trade linkages are directly associated to the synchronization of the economies. These studies usually show that economic growth propagates between trading partners through increased imports, resulting in demand shocks.[1] Other studies show that shocks to U.S. output can significantly affect exports globally through the internationalization of production chains (Tam, 2018; Sevinc and Mata-Flores 2021).

The literature on the role of financial markets and central banks´ monetary policies on the international transmission of shocks has become more relevant since the 2008-2009 financial crisis. Particularly, Sgherri and Galesi (2009) assume that private credit shocks reflect unexpected changes in international financial positions, risk aversion, and banking regulations. The literature on central banks´ monetary policies usually shows that monetary shocks have heterogeneous effects. Pesaran, Schuermann, and Weiner (2004) and Dées *et al*. (2007), among others, suggest that monetary shocks have high effects on the output of economies with high wages and low rigidity in their labor markets.

The literature on the international transmission of macroeconomic shocks among USMCA economies is scarce. In general, the existing studies show that the regional integration process has increased the interdependence and vulnerability among the economies. Some studies suggest that the increase in intra-regional trade and investment since NAFTA has made economic cycles more susceptible to the influence of regional factors (Bayoumi and Swiston, 2008; Kose, Meredith and Towe, 2005). However, other studies suggest that the regional influence of U.S. monetary and trade shocks has declined over time (Pentecôte and Rondeau, 2015; Wei and Lahiri, 2019; Khan, 2020).

The literature on the international transmission of macroeconomic shocks among USMCA economies usually does not consider the influence of other countries and regions of the world. This study describes the interdependencies among the USMCA economies in terms of a global system. We use the GVAR model for this purpose. This methodological approach allows us to: 1) consider the economic and financial heterogeneity of the USMCA economies; 2) assess the interdependencies between the financial and economic variables at the domestic and international levels; and 3) study the trade and financial international transmission channels of shocks for the USMCA economies.

We should point out that the GVAR methodological approach has been used to analyze the transmission of U.S. macroeconomic shocks, among others, by Pesaran, Schuermann, and Weiner (2004), Dées, *et al*. (2007) and Sgherri and Galesi (2009). Specifically, Pesaran, Schuermann, and Weiner (2004) and Dées *et al*. (2007) study the transmission of U.S. monetary shocks in various regions of the world. Sgherri and Galesi (2009) study the international transmission of financial shocks from the United States to the European Union. However, the GVAR methodological approach has not been used to study the transmission of U.S. financial shocks on the economies of Mexico and Canada.[2]

The GVAR approach allow us to model the effects of macroeconomic shocks by considering their influence on the world economy. Here we use the modeling approach proposed by Chudik and Pesaran (2013). This approach allows the estimation of a global system integrated by country-specific models that consistently

1. This literature is rather extensive. See, among others, Frankel and Rose (1998), Kose, Prassad and Terrones (2003), Imbs (2004), Arora and Vamvakidis, (2004), Helbling, *et al*., (2007), Haile and Pozo (2008), Dées and Zorell (2012).

2. We should point out that Khan (2020) analyzes the international trade channel with the GVAR approach for the economies of the USMCA region.

associate the domestic and foreign variables. Domestic variables are endogenous to the model, whereas foreign and global variables are exogenous. For instance, each domestic variable has corresponding foreign variables. They provide a connection between the evolution of the domestic economy and the rest of the world. The foreign variables also reflect the relative importance of the rest of the world in each of the economies of the USMCA region. The approach also allows us to study how the U.S. shocks are transmitted to the economies of Mexico and Canada considering the macroeconomic interdependencies within the region.

Finally, it is important to point out that this study extends the literature of the transmission of U.S. shocks on the USMCA economies. Thus, it provides comparative evidence on the effects and channels of the transmission of U.S. macroeconomic shocks. In this context, we should point out that the USMCA economies are heterogeneous and have different degrees of economic and financial development. These features introduce particularities in the interdependencies within the region and in the transmission channels. Thus, this study allows us to understand better the transmission shock processes, the interdependences and the different degrees of vulnerability of the USMCA economies.

II. METHODOLOGICAL ISSUES

In this study, we use a time-series framework to analyze the effects of the regional integration process on the international transmission of shocks in the USMCA region. The methodology relies on statistical analyses, the estimation of a GVAR model, and the calculation of generalized impulse-response functions. We use the statistical analyses to examine the features of the series. These features are relevant for econometric purposes. We use the GVAR model to characterize the interdependencies between the variables and the countries analyzed. Finally, we study the international transmission channels of shocks originating from the U.S. macroeconomic variables with the GIRF simulations.

The statistical analyses include descriptive statistics and unit-root tests and cointegration tests. We use individual WS-ADF tests (Park and Fuller, 1995), to define the order of integration of the series included in the GVAR model.[3] We use the Johansen trace cointegration tests to evaluate the existence of long-run relationships between the variables of each country analyzed. We assess the stability of the cointegrating relationships using the persistence profile analysis proposed by Lee and Pesaran (1993). This type of analysis allows us to measure the speed of convergence of such relationships toward their equilibrium levels after the occurrence of a shock (Pesaran, 2015).

The statistical analyses also include tests of weak exogeneity of foreign variables. The tests of weak exogeneity allow us to validate the use of the GVAR approach for modelling the macroeconomic series. The tests use the F-statistic proposed by Harbo, *et al*. (1998). The null hypothesis associated with these tests assumes that the country-specific variables do not exhibit long-run feedback effects on the global economy. The validity of the weak exogeneity assumptions is necessary to estimate the parameters in the GVAR model consistently. Furthermore, such validity also allows us to describe the economies analyzed as small open economies (Pesaran, Schuermann and Weiner, 2004).

3. WS-ADF (Weighted-Symmetric ADF) tests take advantage of the temporal reversibility of stationary autoregressive processes and therefore has higher statistical power than traditional ADF tests. For a more detailed explanation see Dées *et al*., 2007.

The statistical analyses also include tests of structural change to assess the structural stability of short-run parameters in the GVAR model. Following Dées *et al*. (2007), we calculate different statistics to assess the existence of structural changes and to determine potential break dates.[4] The tests estimated here use the CUSUM and CUSUMSQ statistics proposed by Ploberger and Krämer (1992) and Brown, *et al*. (1975), respectively. In addition, we use sequential tests for the nonstationary parameters of Nyblom (1989) and the statistics based on quasi-likelihood ratios (QLR), the MW statistic by Hansen (2002), and the APW statistic proposed by Andrews and Ploberger (1994). The calculated statistics also include versions that are robust to heteroscedasticity.

The study of the international transmission of macroeconomic shocks is supported by the estimation of a GVAR model, following the approach of Chudik and Pesaran (2013). Methodologically, the GVAR modelling approach uses an extension of the traditional Vector Autoregressive (VAR) model. This extension, i.e., the *VARX** or *VECX** model in case that variables are cointegrated, incorporates the influence of foreign variables. The complexity of the GVAR modelling approach relates to the number of variables, countries, and time observations included in the model. Indeed, the GVAR modeling approach is closely related to common dynamic factor models, panel data models, and spatial econometrics.

The estimations of the GVAR model use a two-stage procedure.[5] In the first stage, the *VARX** or *VECX** models are specified for each economy, assuming that they are small and open ones. These models include domestic, foreign, and global or dominant variables. The foreign variables are calculated as weighted averages of the other economies' variables in the GVAR model and, like the global variables, are considered weakly exogenous. In the second stage, a global system is built by combining the first-stage estimates using a matrix of predetermined links that reflect the interrelationships between the economies.[6] The estimate must meet dynamic stability assumptions like the ones of the traditional VAR models.[7]

The estimations of the GVAR model allows us to carry two types of complementary analyses. The first one is an analysis of the contemporaneous effects of foreign variables on their domestic counterparts. The results of this analysis allow us to measure instantaneous variations (i.e., impact elasticities) due to changes in the U.S. The second is the analysis of the generalized impulse-response functions. This analysis allows us to study the dynamics and persistence of the international transmission of shocks between the variables and countries in the long run. We use the GIRF functions adapted for the GVAR context proposed by Pesaran, Schuermann, and Weiner (2004).

Here, we analyze the effects of two types of macroeconomic shocks on the economies of Mexico and Canada under the assumption that such shocks are originated in the United States. Specifically, we analyze real and financial shocks. Real shocks relate to GDP and trade; financial ones relate to interest rates and private credit.[8] We reduce the uncertainty due to the existence of structural changes by using the median value of the shocks and 90% confidence intervals. Such intervals are calculated using the sieve bootstrap

4. Different statistics are used here as there is no consensus on the most appropriate tests to study the presence of structural changes in the long-term coefficients in a GVAR context (Dées *et al*., 2007).
5. For a detailed technical description of the estimation and recent developments in GVAR models, see Chudik and Pesaran (2016).
6. This study used fixed weights based on the average value of bilateral trade flows of the countries studied from 1986 to 2019.
7. The correct estimation of a GVAR model assumes that none of the eigenvalues of the characteristic polynomial that define the system is greater than unity. Additionally, it must be verified that the number of unit roots is equal to the difference between the number of cointegrating relationships and total number of endogenous variables in the model.
8 Interest rate shocks are intended to measure the influence of U.S. monetary policy on the rest of the world. Private credit shocks are used to measure the effects of unanticipated changes in financial positions, the perception and aversion of banks and other investors to risk, and regulations on the latter.

method proposed by Dées *et al*., (2007). In addition, to facilitate the analysis of the GIRFs, we present the aggregate regional responses calculated using each country's GDP as a weight.

Garratt *et al*. (2006), argue that the use of GIRFs for estimating impulse-response functions has some limitations. The main limitation relates to the fact that GIRFs do not provide information on the true causal relationships among the variables contained in the GVAR model. However, we should point out that GIRFs provide information on the propagation mechanisms of the shocks between the variables contained in the model (i.e., spillovers). Such consideration explains why we interpret GIRF only in terms of the sensitivity of the response of domestic national variables to the external shocks of the U.S. economy.

We should emphasize that the methodology proposed in this study has three objectives: 1) to characterize macroeconomic interdependencies among the USMCA economies from a global approach; 2) to study the international transmission channels of real and financial shocks of the United States; and 3) to infer the potential vulnerability of Mexico and Canada due to international trade and financial integration processes with the United States. These objectives are relevant to studying the feasibility of implementing coordinated regional policies to foster economic growth and financial stability in the United States, Mexico and Canada.

III. DATABASE AND STATISTICAL ANALYSIS

Here we use quarterly macroeconomic variables for 33 economies from 1986: Q1 to 2019: Q4.[9] The countries included in the empirical analysis and the regionalization considered are listed in Table 1. This study includes several macroeconomic indicators representative of six geographical regions comprising economies with different levels of economic and financial development. The selection of economies included in the database is justified since they generated approximately 90% of the value of world GDP in 2016 (Mohaddes & Raissi, 2020).

Table 1. List of economies and regions included in the GVAR model.

European Union	***Asia***	***Advanced Economies***
Austria	India	Australia
Belgium	Indonesia	Norway
Finland	South Korea	New Zealand
France	Malaysia	Sweden
Germany	Philippines	Switzerland
Italy	Thailand	***Africa and the Middle East***
The Netherlands	Singapore	South Africa
Spain	***North America***	Saudi Arabia
South America	Canada	Turkey
Argentina	United States	China
Brazil	Mexico	Japan
Chile		United Kingdom
Peru		

Source: authors' own elaboration.

9 To avoid possible distortions due to the introduction of the euro in international markets as of 1999, we model the indicators of eight European countries (Austria, Belgium, Finland, France, Germany, Italy, the Netherlands, and Spain) as an aggregate representative economy of the European Union. The calculation of this artificial economy was based on the procedure described by Dées *et al*. (2007, p.9).

We use seven macroeconomic indicators expressed in real terms to characterize the interdependencies between countries. These indicators include: 1) real GDP (y_{it}); 2) inflation rates (Dp_{it}); 3) deflated exchange rates (ep_{it});[10] 4) short-term interest rates (ρ^{s}_{it}); 5) the value of each country's total trade flows ($trade_{it}$); 6) credit provided to the non-financial private sector ($cred_{it}$); and 7) Brent oil prices ($poil_t$).[11] Except for the private credit and total trade variables, the remaining variables were retrieved from the database compiled by Mohaddes and Raissi (2020), also known as the "2019 Vintage".[12] Table A1 shows a detailed description of the indicators considered and their respective sources.

To estimate the econometric model, we consider the following variable transformations:

$$\begin{aligned} &y_{it} = \ln(GDP_{it}), \quad Dp_{it} = p_{it} - p_{it-1}, \quad p_{it} = \ln(CPI_{it}), \quad ep_{it} = \ln\left(\frac{E_{it}}{CPI_{it}}\right), \\ &r_{it} = 0.25 \times \ln\left(1 + \frac{R_{it}}{100}\right), \quad rtrade_{it} = \ln\left(\frac{Exp_{it} + Imp_{it}}{CPI_{us,t}}\right), \quad rcred_{it} = \ln\left(\frac{cred_{it}}{cpi_{US,t}}\right), \quad poil_{it} = \ln(poil_t) \end{aligned} \tag{1}$$

where GDP_{it} is the real Gross Domestic Product at time t for country i; CPI_{it} is the consumper price index with base period 2010 = 100; E_{it} is the nominal exchange rate in terms of US dollar; r_{it} is the quarterly short-term nominal interest rate; Exp_{it} and Imp_{it} are the seasonal adjusted nominal values of each country's total export and import flows with the world; $cred_{it}$ is the nominal value of credit provided by all financial intermediaries to the non-financial private sector; and $poil_t$ the quarterly average of the daily closing prices of Brent crude oil. Thus, the database consists of a total of 149 series and 20,264 observations.[13]

We assume that international trade is one of the main mechanisms in the international transmission of business cycles (Imbs, 2004; Baxter and Kouparitsas, 2005). Therefore, bilateral trade flows are used to calculate the foreign variables in the GVAR model using the following expression:

$$\mathbf{x}^{*}_{it} = \sum\nolimits_{j=0}^{N} w_{ij}\,\mathbf{x}_{jt} \tag{2}$$

where $\mathbf{x}^{*}_{it}$ is the calculated value of the foreign variables; w_{ij}, reflects the share of country *i's* that is part of total trade in country *j's* during the period analyzed; and $\mathbf{x}_{jt}$ is the value of country *j's* domestic variables. Particularly, in this study we use fixed trade-weights calculated from the average value of bilateral trade flows recorded from the years 1986 to 2019.[14] The countries in the GVAR model are linked by the weight, w_{ij}, which represents closeness of economic relationships between countries.

10. Exchange rates are evaluated as the domestic currency price of the U.S. dollar (LCU/USD). Thus, an increase in the exchange rate reflects the depreciation of the domestic currency. The GVAR approach considers the effects of domestic and foreign exchange rate changes.

11. The oil price series is used in the GVAR model as a common factor to model the effects of common shocks on the global economy. We assume that oil prices can potentially affect the dynamics of the world economy but not vice versa.

12. See Mohaddes and Raissi (2020) for a detailed description of the construction of variables for the economies that have adopted the euro as their legal currency.

13. Owing to constraints in data availability, the number of domestic variables varies across countries. This is evident in the cases of Argentina's consumer price index, South Africa's total trade, Saudi Arabia's interest rate, and private credit in Argentina, Brazil, Peru, and the Philippines.

14. The use of fixed weights is justified for both economic and econometric reasons. In economic terms, the period under analysis is characterized by the gradual opening of economies worldwide to international trade and investment. In econometric terms, here we follow the study by Dées *et al*. (2007) which shows that the estimates of GVAR models tend to be relatively robust regardless of the type of weights used.

Table 2 shows the weight matrix based on the bilateral trade flows used for the calculation of the foreign variables.[15] In particular, the table shows that during the period analyzed, the contributions of the United States to the total trade of Canada and Mexico were, respectively, 72.28% and 71.21%. However, the contributions of Canada and Mexico to total U.S. trade were only 21.11% and 14.30%, respectively. The same table shows the magnitude of North America's contributions to the total trade of South American countries, China, and the European Union. The magnitudes of the contributions suggest that trade could be a relevant channel for the transmission of macroeconomic shocks in such regions.

Table 2. Weight matrix used for the calculation of foreign variables in the GVAR

Country/ region	*Canada*	*U.S.*	*Mexico*	*China*	*European Union*	*South America*	*Rest of the World*	*Sum*
Canada	0.0000	0.7228	0.0288	0.0573	0.0586	0.0126	0.1199	1.0000
U.S.	0.2111	0.0000	0.1430	0.1390	0.1532	0.0351	0.3186	1.0000
Mexico	0.0274	0.7121	0.0000	0.0714	0.0677	0.0239	0.0976	1.0000
China	0.0197	0.2090	0.0137	0.0000	0.1634	0.0491	0.5451	1.0000
European Union	0.0181	0.1850	0.0156	0.1185	0.0000	0.0408	0.6219	1.0000
South America	0.0248	0.1943	0.0302	0.1644	0.1832	0.0000	0.4031	1.0000

Weights are calculated based on the average value of real bilateral trade flows between countries from 1986 to 2019. The columns in the table represent the contribution of each country to the total trade of the countries indicated in the rows. The main diagonal of the matrix contains zeros because countries' trade with themselves is not considered. The "Rest of the world" column refers to countries contained in the database that are not presented in the table.

Source: authors' own estimations with data from the **International Monetary Fund** (IMF).

Table 3 shows the results of the unit root analysis, which considers the domestic, foreign, and global variables. In general, the table shows that most of the variables studied are stationary in their first differences; that is, the variables are $I(1)$. However, the same table presents some discrepancies in the inflation rate series associated with the domestic variables.[16] These discrepancies may be due to the existence of structural changes and possible distortions in the tests owing to the small size of the sample analyzed. For consistency, we assume that all variables are approximately $I(1)$. This assumption allows us to distinguish between short- and long-run relationships among the series of variables.

15. For space limitations and ease of analysis, only the weight matrix for North American economies and their main trading partners is reported here. However, it should be emphasized that the matrix used for the estimation of the GVAR model in the empirical analysis includes the information of all countries in the database. This matrix is available on request from the authors.

16. Following Cesa-Bianchi *et al*. (2012), we prefer to use the inflation rate series because the econometric problem of over-differencing an $I(0)$ series turns out to be less than including a potential $I(2)$ series, as is the case with consumer price indexes.

Table 3. WS-ADF unit root test results

Serie	Domestic variables				Foreign and dominant variables			
	Levels		First differences		Levels		First differences	
	# of series	*Reject H0*	*# of series*	*Reject H0*	*# of series*	*Reject H0*	*# of series*	*Reject H0*
GDP	26	1	26	26	26	0	26	26
Inflation rate	26	21	26	26	26	10	26	26
Total trade	25	0	25	25	26	0	26	26
Exchange rate	25	0	25	25	26	0	26	26
Interest rate	25	14	25	24	26	3	26	26
Private credit	21	0	21	20	26	0	26	26
Crude oil prices					1	0	1	1

The null hypothesis of the WS-ADF tests assumes that the analyzed series contains a unit root. The number of rejections of the null hypothesis for each variable considered a 95% confidence level. The tests consider the inclusion of a constant and deterministic trend as an exogenous regressor. The series of levels are those of the original values expressed in natural logarithms. The series in the first differences expresses the first differences of the original series in logarithms.

Source: authors' own estimations using data from Mohaddes and Raissi (2020), **IMF-DoTS**, and the Bank for International Settlements.

IV. ECONOMETRIC ESTIMATIONS AND THE GIRF SIMULATIONS OF REAL AND FINANCIAL SHOCKS

Here we use the GVAR approach to examine the international transmission channels of the U.S. shocks from a global perspective. The estimation of the GVAR model requires the specification of individual *VARX** models for each country, considering that they include domestic, foreign, and global variables. The estimation of such models considers cointegration analysis and, where appropriate, the estimation of vector error-correction models (*VECMX**). Here, 26 representative models were defined for the countries contained in the database, including those of the European Union. The variables contained in each model are described in Table 4.

Table 4 shows two specifications for the *VARX** models. The first specification, i.e. the U.S. model, assumes that the United States behaves as a relatively closed economy. Like Dées *et al*. (2007) and Eickmeier and Ng (2015), we assume that the U.S. exchange rate is determined abroad and that foreign variables do not affect the U.S. interest rate nor its private credit. This assumption emphasizes the dominance of the U.S. economy and the use of the dollar in international financial markets. By contrast, in the second specification, (i.e. all economies but the US), the countries in the database are modeled as small, open economies, considering the influence of all foreign variables on their domestic counterparts.

This study uses the oil price series as an exogenous variable of global influence following the dominant unit approach of Chudik and Pesaran (2013).[17] The approach assumes that idiosyncratic oil price shocks have a significant impact on all economies in the world. Thus, we assume that oil price shocks have feedback effects only on real GDP and inflation rates. Furthermore, we assume that the effects of individual economies on oil prices are negligible. In this context, oil prices have become a common factor for all economies studied.

17. This specification of the GVAR model differs from those proposed by Dées *et al*. (2007) and Cesa-Bianchi *et al*. (2012), who assume that oil prices are endogenous to the dynamics of economic activity in the United States.

Table 4. Variables included in the country-specific *VARX models.**

Serie	U.S. Model		All economies but the U.S.	
	Domestic	*Foreign*	*Domestic*	*Foreign*
GDP	1	1	1	1
Inflation rate	1	1	1	1
Total trade	1	1	1	1
Exchange rate	0	1	1	0
Interest rate	1	0	1	1
Private credit	1	0	1	1
Crude oil prices	0	1	0	1

1 and 0 indicate that the variable is included in or excluded from the model, respectively. Oil price is considered the dominant variable in the GVAR model. The dominant variable model considers only the feedback effects from oil prices on real GDP and inflation rates. The dominant unit considers the estimation of the univariate model in first differences.

Source: authors' own elaboration.

Table A2, included in the appendix of this paper, summarizes the order of lags and the range of cointegration used to estimate the *VARX** models. The maximum number of lags for the domestic and foreign variables is set to three. Likewise, the optimal order of lags was selected using the Akaike information criterion (AIC). The range of cointegration of the same models was determined using the Johansen trace statistic test using a significance level of 5%. We guarantee the robustness of the GVAR model with an analysis of the persistence profiles of the cointegrating relationships (Lee and Pesaran, 1993). The results of such analysis are shown in Figure A4 in the appendices.

Table A3, included in the appendix, shows the results of the exogeneity tests of the foreign and dominant variables in the *VARX** models. The table shows that, in most cases, it is not possible to reject the null hypothesis of weak exogeneity of the variables at different levels of statistical significance. However, the same table shows that there are some variables for which it is impossible to reject the null hypothesis. To analyze the robustness of the results, the cointegration tests were re-estimated, excluding these variables, without finding quantitatively different results.[18] Given these findings, we decided to keep the models that assume that all the variables were weakly exogenous.[19]

Table 5 shows the results of the analysis of the contemporaneous effects of the foreign variables on their domestic counterparts in the *VARX** models. The estimated coefficients can be interpreted in terms of impact elasticities. Particularly, the table shows that most coefficients are significant and positive. Specifically, the table shows that a 1% increase in world economic activity is related to an increase in economic activity of 0.432% in the United States, 0.3830% in Mexico, and 0.3526% in Canada. The same table also shows that a 1% increase in world inflation is related to a 0.6265% increase in inflation in Canada and a 0.1499% increase in inflation in the United States.[20]

18. The results of the robustness tests are not shown in this paper for space reasons but are available upon request from the authors.

19. There are economic reasons for treating foreign variables as exogenous. Variables that do not meet the exogeneity assumption belong to relatively small economies at the global level. Therefore, it is reasonable to assume that the domestic variables of these countries are affected by their foreign counterparts.

20. The absence of significant relationships between Mexico's inflation and interest rates for the rest of the world can be explained by the existence of price controls during the 1980s and monetary policies based on the nominal exchange rate anchor until 1995 (Clavijo and Valdivieso, 2000).

Table 5 also shows that North American trade is positively related to the dynamics of world trade. A 1% increase in world trade is related to an increase of 0.9534% in Mexico, 0.8693% in Canada, and 0.7129% in the United States. The coefficients of interest rates show that only Canada is positively related to global interest rate dynamics. Furthermore, the table shows that a 1% increase in world private credit is associated with an increase of 1.3813% in Canada's credit, and 1.2732% in Mexico. The differences in the magnitudes of the coefficients imply that North American countries are linked, in decreasing order, to the world economy through private credit, international trade, real GDP and the inflation rate.

Table 5. Contemporaneous effects of foreign variables on their domestic counterparts

Country/Serie	Domestic variables				
	GDP	*Inflation rate*	*Total Trade*	*Interest rate*	*Private credit*
Canada	0.3526 ***	0.6126 ***	0.8693 ***	0.2795 *	1.3813 ***
United States	0.4232 ***	0.1499 ***	0.7129 ***		
Mexico	0.3830 *	-0.5524	0.9534 ***	-0.1421	1.2732 ***

Asterisks (*,**, and ***) indicate the statistical significance levels of the coefficients at 10%, 5%, and 1%, respectively. Estimates consider the calculation of Newey-West t-statistics, consistent with the presence of heteroscedasticity and autocorrelation.

Source: authors' own estimations using MATLAB routines included in the GVAR Toolbox 2.0, developed by Smith and Galesi (2014).

Table 6. Structural change test results in the GVAR model

Serie/ Statistic	*GDP*	*Inflation rate*	*Total trade*	*Exchange rate*	*Interest rate*	*Private credit*	*Total breaks*	*Total coefficients*	*(%)*
CUSUM	5	3	5	3	4	1	21	148	14.1892
CUSUMQ	4	5	2	4	6	1	22	148	14.8649
Nyblom	4	7	4	3	9	1	28	148	18.9189
Robust-Nyblom	4	3	2	1	7	0	17	148	11.4865
QLR	7	17	6	6	20	3	59	148	39.8649
Robust-QLR	1	0	2	1	1	1	6	148	4.0541
MW	14	12	6	9	20	5	66	148	44.5946
MW-Robust	6	1	2	1	1	1	12	148	8.1081
APW	7	16	6	6	20	3	58	148	39.1892
APW-Robust	2	0	2	1	1	1	7	148	4.7297

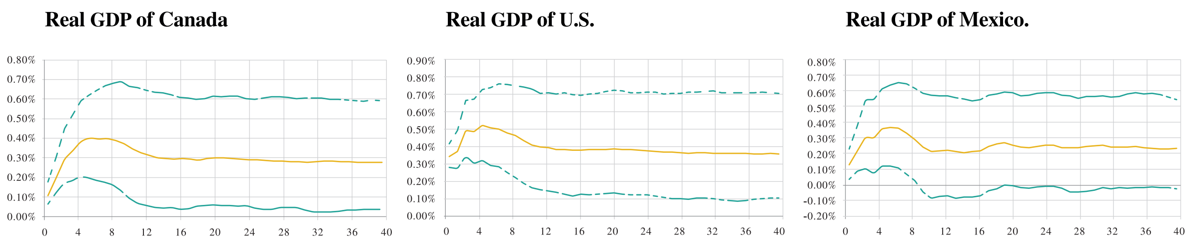
The CUSUM and CUSUMSQ statistics are based on the cumulative sum of the residuals of the regressions estimated by ordinary least squares. The Nyblom, QLR, and MW tests are based on the calculation of sequential statistics for a single break on an unknown date. The statistics labeled "Robust" denote the robust version of the statistics for the presence of heteroscedasticity. The critical values of the tests consider a significance level of 5%.

Source: authors' own estimations using MATLAB routines included in GVAR Toolbox 2.0, developed by Smith and Galesi (2014).

Table 6 shows the results of the analysis of structural changes in the GVAR model. The table indicates the existence of structural changes in most of the analyzed series. In particular, the highest numbers of breaks occur in the inflation and interest rate series. These findings can be explained under the consideration that the analyzed period was characterized by different inflationary crises during the 1980s and changes in monetary policies due to the global financial crisis of 2008-2009. The same table also shows that the number of breaks is significantly reduced using heteroscedasticity-robust versions of the structural-change statistics.

We use the GVAR model to study the vulnerability of the USMCA and other economies at the global level to real and financial shocks in the U.S. We study the effects of a one standard deviation exogenous shock on real GDP, interest rates, trade, and private credit. The simulations were obtained from the GIRF calculations considering a forecast horizon of 40 quarters. We also use the sieve bootstrap method with 1,000 replications to reduce the potential effects of structural changes in the series. We use the resampling method proposed by Dées *et al*. (2007) to calculate the median values of the GIRFs and their 95% confidence intervals. These calculations allow us to simplify the analysis.

Figure 1. GIRFs to a positive shock of 1 SD to U.S. real GDP



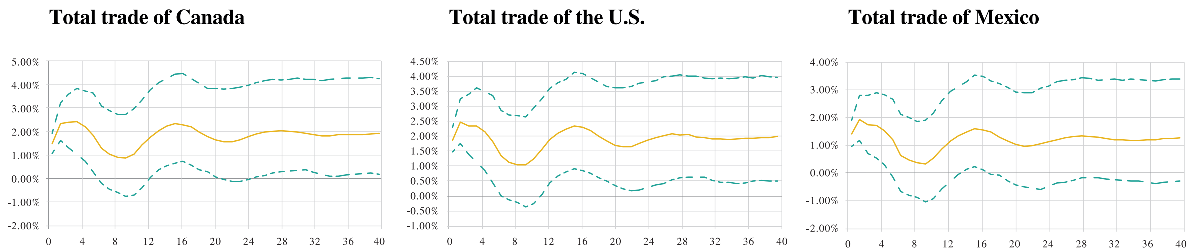
The solid lines (yellow) represent the median 1 standard deviation (S.D.) shock response to U.S. real GDP, calculated using the sieve bootstrapping method with 1,000 replications. The dashed lines (green) represent confidence intervals at the 90% level.

Source: authors' own estimations using MATLAB routines included in GVAR Toolbox 2.0, developed by Smith and Galesi (2014).

Figure 1 shows the effects of a one-standard-deviation positive shock on the U.S. real GDP. This figure shows that the shock caused an instantaneous increase of 0.3452% in the U.S. GDP increased to a maximum of 0.5247% in the fourth quarter. The effects of this shock are permanent for the U.S. GDP and stabilized at around 0.3809% starting in the eighth quarter. The same figure shows that the largest spillover effects of this shock are present in the GDP of Canada and Mexico. Canada's GDP registers a maximum increase of 0.4053% and Mexico's of 0.3776%. The effects of the same shock turn out to be permanent for Canada, and in the case of Mexico, they are not significant after eight periods following the shock.

Figure 2 shows the effects of a one-standard-deviation positive shock on U.S. real trade flows. This figure shows that the shock causes an instantaneous increase of 1.8547% in total U.S. trade, which increases to a peak of 2.4758% in the subsequent quarter. The effects of this shock are permanent and stabilize at 1.8516% after 17 quarters. The same figure also indicates that the most significant impact of the shock is observed in Canada, where there is a maximum trade increase of 2.4127%. In Mexico, the increase is slightly lower at 1.9289%. The oscillations of the impulse-response functions can potentially be explained by the readjustment of trade at the global level due to changes in U.S. import demands.

Figure 2. GIRFs to a positive shock of 1 SD to U.S. real trade flows

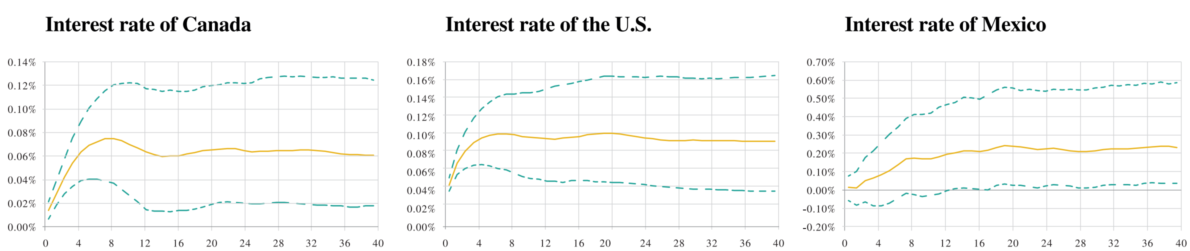


The solid lines (yellow) represent the median 1 standard deviation (S.D.) shock response to U.S. trade flows, calculated using the sieve bootstrapping method with 1,000 replications. The dashed lines (green) represent confidence intervals at the 90% level.

Source: authors' own estimations using MATLAB routines included in GVAR Toolbox 2.0, developed by Smith and Galesi (2014).

Figure 3 shows the effects of a one-standard-deviation positive shock on the U.S. nominal interest rate. This figure shows that the shock caused an instantaneous increase of 0.0470% in the U.S. interest rate, which increased to a maximum of 0.1054% in the seventh quarter. The effects of this shock are also permanent and stabilize at around 0.0995% starting in the ninth quarter. The figure also indicates that the impact of the interest rate shock results in a maximum increase of 0.2281% in Canada's interest rate and 0.0773% in the case of Mexico.[21] These findings potentially reflect certain similarities in monetary policy among the USMCA economies.

Figure 3. GIRFS to a positive shock of 1 SD to the U.S. nominal interest rate



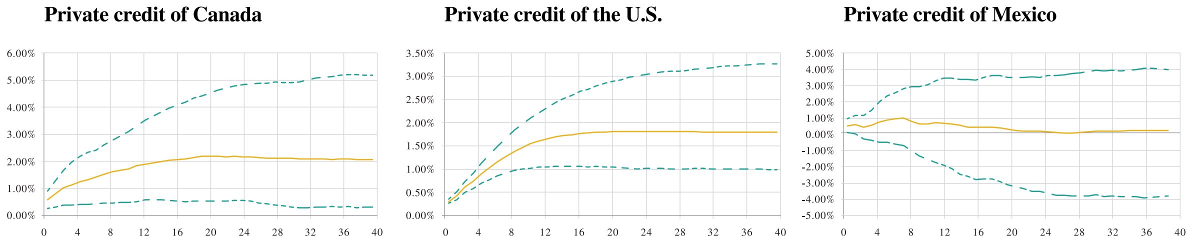
The solid lines (yellow) represent the median 1 standard deviation (S.D.) shock response to U.S. interest rate, calculated using the sieve bootstrapping method with 1,000 replications. The dashed lines (green) represent confidence intervals at the 90% level.

Source: authors' own estimations using MATLAB routines included in GVAR Toolbox 2.0, developed by Smith and Galesi (2014).

Figure 4 shows the effects of a one-standard-deviation positive shock on U.S. real private credit. The figure shows that the shock induces an instantaneous increase of 0.355% in U.S. private credit, which can increase up to a maximum of 1.812% twenty-three quarters after the initial shock. The figure also shows evidence that the only significant effect of the credit shock is observed in Canada, with a peak of credit increase of 2.192%. These findings may reflect the similarities in financial development and market integration between the U.S. and Canada.

21. It is noteworthy that the restrained response of Mexico to the U.S. interest rate shock may be attributed to the existence of distinct monetary policy regimes and the heightened volatility experienced by the country during the 1980s and 1990s.

Figure 4. GIRFs to a positive shock of 1 SD to U.S. real private credit



The solid lines (yellow) represent the median 1 standard deviation (S.D.) shock response to U.S. private credit, calculated using the sieve bootstrapping method with 1,000 replications. The dashed lines (green) represent confidence intervals at the 90% level.

Source: authors' own estimations using MATLAB routines included in GVAR Toolbox 2.0, developed by Smith and Galesi (2014).

The main findings of the econometric estimations can be summarized as follows: 1) The USMCA economies are contemporaneously linked to the world economy mainly through private credit, international trade and real GDP; 2) shocks on U.S. GDP and U.S. trade flows have higher influence in Canada than in Mexico; 3) shocks on U.S. interest rates have higher influence in Mexico than in Canada; 4) shocks on U.S. private credit may have influence in Canada, but not in Mexico; 5) the private credit and the international trade channels are the most important ones for the transmission of international macroeconomic shocks; and, 6) there is evidence of structural changes in the behavior of the macroeconomic variables during the period analyzed.

CONCLUSIONS AND DISCUSSION

Here we have analyzed the international transmission of U.S. real and financial shocks on the USMCA region using a global approach. The study has relied on statistical analyses, the estimation of a GVAR model, and the calculation of generalized impulse-response functions. Particularly, the GVAR model was estimated following the methodology proposed by Chudik and Pesaran (2013). The impulse-response functions were used to study the international transmission channels of the shocks from the U.S. economy to the ones of Mexico and Canada. The analysis has relied on quarterly time-series for the period 1986:Q1 to 2019:Q4.

The main findings of the descriptive analysis point to the relative importance of the trade relationships among the USMCA economies. They show that Canada and Mexico are highly dependent on U.S. trade flows. However, U.S. trade relations are relatively more diversified, with significant contributions from Canada, Mexico, China, and the European Union. In this context, the findings suggest that international trade may be a relevant channel for the transmission of regional and extra-regional macroeconomic shocks. Furthermore, the results of the unit root tests suggest that the inflation and interest rate series show certain instabilities that should be studied further.

The findings of the econometric estimations show that: 1) The USMCA economies are contemporaneously linked to the world economy mainly through private credit, international trade and real GDP; 2) shocks on U.S. GDP and U.S. trade flows have higher influence in Canada than in Mexico; 3) shocks on U.S. interest rates have higher influence in Mexico than in Canada; 4) shocks on U.S. private credit may have influence in Canada, but not in Mexico; 5) the private credit and the international trade channels are the most important ones for the transmission of international macroeconomic shocks; and, 6) there is evidence of structural changes in the behavior of the macroeconomic variables during the period analyzed.

These findings have implications for macroeconomic policy purposes. The predominance of private credit channel justifies the existence of coordinated regulations and common institutional arrangements to promote well-functioning financial markets in the USMCA region. The relevance of the international trade channel suggests that U.S. trade policies must be considered by Mexican and Canadian policymakers to analyze and implement economic-growth strategies. Finally, the differences observed in the GIRF analysis regarding the effects of the U.S. shocks suggest that the economic integration process of the USMCA region has been more complex than what it is usually believed.

Finally, it should be emphasized that this study provides new findings regarding the international transmission of macroeconomic shocks originating in the United States. However, we should recognize that the study has methodological limitations. The first limitation relates to the assumption that the relationships are linear and stable over time for all the countries and all the series. The second one is associated with the use of a matrix based on bilateral trade flows to support the GVAR analysis approach. The third limitation is that GIRFs do not allow the identification of shocks. Without doubt, overcoming these limitations may be useful to promote the economic and financial development in the USMCA region.

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Appendices

Table A1. Description and sources of the variables used in the GVAR model.

Acronym	*Serie*	*Description*	*Unit of measurement*	*Source*	*No. of series*
Domestic and foreign variables					
Y	Real GDP	Index 2010 = 100	Index	IMF/ Haver Analytics*	33
Dp	Inflation rates	Inflation rate end of period consumer prices 2010 = 00	Annual rate of change (%)	IMF/ Haver Analytics*	33
Ep	Deflated exchange rate	Nominal bilateral exchange rate (LCU/USD) vis-a-vis the U.S. dollar deflated using consumer prices	LCU/USD	IMF*	32
R	Shor-term interest rate	Short-term nominal interest rate	Quarterly percentage	IMF*	32
Rtrade	Total trade	The sum of the value of exports and imports in U.S. dollars deflated using the U.S. consumer price index.	U.S. Dollar	IMF-DoTS	32
Rcredit	Private credit	The value of total credit provided by all intermediaries to the non-financial private sector.	U.S. Dollar	Bank for International Settlements	21
Dominant variable					
Poil	Crude oil prices	Brent crude oil price	U.S. Dollar	Bloomberg*	1
Additional variables					
Weights	Trade weights	Sum of the nominal value of bilateral exports and imports divided by the value of each country's total trade with the world.	Percentage	IMF-DoTS	33
PPP	GDP (PPP)	Value of real GDP adjusted for purchasing power parity (PPP) over the period 1990 to 2019.	U.S. Dollar	World Bank	33

The asterisk (*) denotes that the series were retrieved from the "Global VAR Database 1979Q2-2019Q4" compiled by Mohaddes and Raissi (2020). All variables were adjusted seasonally using the X-13 ARIMA procedure. The value of trade weights was calculated using the MATLAB codes available in GVAR Toolbox 2.0 written by Smith and Galesi (2014).

Source: authors' own elaboration.

Table A2. Lag order and cointegration rank in the *VARX models**

Country/region	*VARX* order*		*Rank of cointegration*	*Country/region*	*VARX* order*		*Rank of cointegration*
	p_i	q_i			p_i	q_i	
North America				***European Union***	3	3	4
Canada	1	1	5	***Advanced Economies***			
United States	3	1	2	Australia	2	2	3
Mexico	3	1	3	Norway	2	1	3
South America				New Zealand	3	2	2
Argentina	3	3	3	Sweden	2	3	3
Brazil	3	3	2	Switzerland	2	3	3
Chile	3	3	3	***Africa and the Middle East***			
Peru	3	3	3	South Africa	2	1	2
Asia				Saudi Arabia	2	1	3
India	3	3	2	Turkey	2	1	2
Indonesia	3	1	3	China	2	1	4
South Korea	3	1	4	Japan	2	3	4
Malaysia	2	1	3	United Kingdom	2	2	3
Philippines	3	2	4				
Thailand	3	3	5				
Singapore	2	3	3				

The optimal lag order of the *VARX** (*p*,*q*) model was selected using the Akaike information criterion (AIC). The maximum number of lags for the domestic and foreign variables is set to three. The range of the cointegration space of the *VARX** models was calculated using the trace statistic test considering critical levels of 5%. Asymptotic critical values were retrieved from Mackinnon. Haugh and Michelis (1999). The specification of the cointegration tests considers the inclusion of an unrestricted intercept and a restricted trend following Case IV described by Pesaran *et al*. (2004).

Source: author's own estimations using MATLAB routines included in the GVAR Toolbox 2.0, developed by Smith and Galesi (2014).

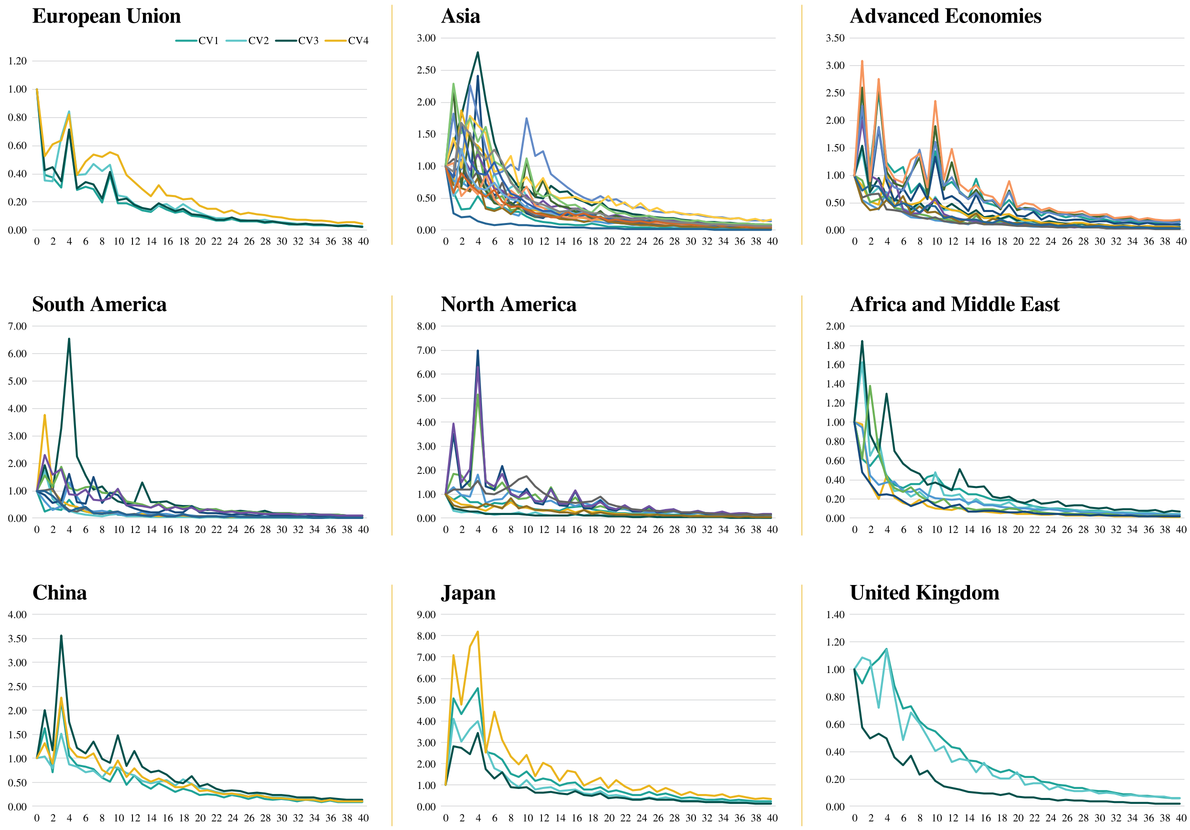
Table A3. Results of weak exogeneity tests of foreign and dominant variables

Country/region	*F-Statistic*	*Critical values*			*GDP*	*Inflation rate*	*Total trade*	*Exchange rate*	*Interest rate*	*Private credit*	*Oil prices*
		90%	*95%*	*99%*							
North America											
Canada	F(5,113)	1.8989	2.2946	3.1835	4.2382	0.8472	1.9400		1.8331	1.2355	2.0799
United States	F(2,119)	2.3477	3.0724	4.7880	1.3309	1.2809	1.8911	0.9603			0.2454
Mexico	F(3,115)	2.1320	2.6835	3.9565	1.3607	1.2158	0.1724		9.0230	0.1506	0.4775
South America											
Argentina	F(3,103)	2.1377	2.6928	3.9776	0.6638	1.2726	0.0132		2.3520	0.7559	0.3220
Brazil	F(2,104)	2.3543	3.0837	4.8152	4.6570	8.1424	2.5379		10.1122	0.8620	1.0376
Chile	F(3,115)	2.1320	2.6835	3.9565	0.1029	4.6649	0.5963		2.1938	1.1321	1.1284
Peru	F(3,116)	2.1316	2.6828	3.9550	0.2148	1.2071	0.1493		2.8748	0.5253	2.4362
Asia											
India	F(2,116)	2.3489	3.0744	4.7929	0.8402	2.0389	0.2666		0.7734	0.0184	0.3177
Indonesia	F(3,115)	2.1320	2.6835	3.9565	2.0897	0.7235	1.1489		0.9704	0.5486	0.8435
South Korea	F(4,114)	1.9948	2.4513	3.4882	0.8419	1.7239	0.8092		0.6009	0.4362	1.0603
Malaysia	F(3,115)	2.1320	2.6835	3.9565	1.1445	3.9692	3.5004		1.6501	0.6084	2.3556
Philippines	F(4,115)	1.9943	2.4506	3.4867	1.4370	0.5659	1.2921		1.7208	0.9932	2.1022
Thailand	F(5,113)	1.8989	2.2946	3.1835	1.4192	1.0354	0.6435		1.6558	1.7898	1.6799
Singapore	F(3,115)	2.1320	2.6835	3.9565	1.7467	2.3307	0.0522		1.5499	1.6984	0.3538
European Union	F(4,114)	1.9948	2.4513	3.4882	2.4807	0.4769	1.1382		0.6537	0.7284	0.2350
Advances Economies											
Australia	F(3,115)	2.1320	2.6835	3.9565	0.3483	0.2764	1.5611		0.1716	0.1635	0.7868
Norway	F(3,115)	2.1320	2.6835	3.9565	0.4544	5.8069	1.3660		0.6517	1.3305	1.4379
New Zealand	F(2,116)	2.3489	3.0744	4.7929	0.0789	0.5986	2.7431		4.8776	0.4779	0.1681
Sweden	F(3,115)	2.1320	2.6835	3.9565	1.7504	2.2852	0.2283		0.5406	1.0255	2.7566
Switzerland	F(3,115)	2.1320	2.6835	3.9565	2.9650	2.1892	0.9169		0.1264	1.6794	0.1886
Africa and Middle East											
South Africa	F(3,117)	2.1311	2.6821	3.9535	1.1659	0.5681	0.5890		2.3765	3.5095	0.4902
Saudi Arabia	F(3,115)	2.1320	2.6835	3.9565	1.7467	2.3307	0.0522		1.5499	1.6984	0.3538
Turkey	F(2,116)	2.3489	3.0744	4.7929	2.3145	0.2583	2.2974		0.0308	0.3629	0.3611
China	F(4,100)	2.0019	2.4626	3.5126	1.1004	2.8771	1.4449		0.9323	0.6969	1.5252
Japan	F(4,114)	1.9948	2.4513	3.4882	1.9831	2.0217	0.3767		2.3496	1.2069	0.2993
United Kingdom	F(3,115)	2.1320	2.6835	3.9565	2.2662	0.6881	1.2931		0.7829	0.3439	0.5301

The null hypothesis of the test assumes that the analyzed variable is weakly exogenous. The null hypothesis was rejected if the test statistic was greater than the critical values at different levels of statistical significance. Values in bold indicate the rejection of the null hypothesis at a critical level of 99%.

Source: authors' own estimations using MATLAB routines included in GVAR Toolbox 2.0, developed by Smith and Galesi (2014).

Figure A4. Persistence profiles of cointegrating relationships in *VARX models**



The graphs present the median values of the persistence profiles of the cointegration relationships used for the estimation of the GVAR model. The median value was calculated using the sieve bootstrap method from 1,000 simulations.

Source: authors' own estimations using MATLAB routines included in the GVAR Toolbox 2.0, developed by Smith and Galesi (2014).