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Common and Idiosyncratic Components of Latin American Business Cycles Connectedness

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Common and idiosyncratic components of Latin American business cycles connectedness*

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Abstract

This paper investigates the evolution of business cycles synchronization in Latin America since the 1990's. To do so, a Vector Autoregressive model is fed, alternatively, with the countries' Industrial Production Indexes and with these series filtered by the US financial conditions index, which is considered as a common component affecting business cycles in the region. Additionally, a Markov switching model is estimated to identify regional recessions. Our findings indicate that business cycles connectedness rise significantly during regional recessions and that the common factor plays an important role. The evidence supports the usefulness of policy coordination among Latin American economies to cushion the spillover effects of exogenous shocks, and helps to identify subgroups of countries for which such coordination is recommendable.

Keywords: Connectedness indexes, Vector autoregressive analysis, Markov switching models, policy coordination, Latin American business cycles.

JEL Classification: C32; E32; F44; N16.

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"The idea of general interdependence among the various part of the economic system has become by now the very foundation of economic analysis. Yet, when it comes to the practical application of this theoretical tool, modern economists must rely exactly as Quesnay did upon fictitious numerical examples".Leontief (1951)

1 Introduction

Since the physiocrats, the concept of connectivity has been in the heart of economic analysis. Whenever a national economy, the international financial architecture or its underlying macroeconomic fundamentals are described, connectedness lies in the center stage. Notwithstanding, because connectivity has not been always clearly defined, its quantitative measurement has not been properly framed. So, Leontief's phrase cited above is not entirely outdated.

In an attempt to correct this flaw in the discipline, Diebold and Yilmaz (2015) came up with a model to measure the connectivity within a system. Their methodology has been recently applied to several subfields in economics and finance and, thanks to its simplicity and accuracy, has the potential of becoming a regular toolkit in measuring connectivity in any discipline[1]. Conceptually, Diebold and Yilmaz's empirical framework lays over the argument built by Acemoglu et al. (2012). In that work, Acemoglu and his coauthors challenged Lucas (1977)'s view that idiosyncratic shocks can be averaged out thanks to diversification and claimed that these disturbances might provoke cascades effects and, hence, have a potential aggregate impact in an interconnected system.

Diebold and Yilmaz's methodology is likely most useful in international economics, as it is known since Backus et al. (1992) that countries' business cycles are often connected and share common patterns. After Backus and coauthors' seminal work, an extensive literature has studied the cyclical synchronization in rich nations (see Canova et al. (2007), among others). In an interconnected world, linkages between developed and developing economies' can also be expected to be important and, hence, have been studied by Kose et al. (2003) and Ductor and Leiva-León (2016). Nevertheless, little is known about the nature of these relations among developing nations.

Not long ago, emerging countries started to move away from the traditional center-periphery dimension and to build solid trade and financial links among themselves. In particular, Latin America has experienced important transformations in

[1]Diebold and Yilmaz (2015)'s model has been used in different areas ranging from business cycles connectedness (Bataa et al. (2018)) to sovereign bond markets (Fernández-Rodríguez et al. (2016)), foreign exchange markets (Baruník et al. (2017)) and even oil and equity markets (Maghyereh et al. (2016)).

its countries' interconnectedness since the 1990's with potential consequences for its business cycles' comovements. I.e, regional trade agreements flourished and incipient financial links have spread among Latin American countries. In addition, macroeconomic instability, which was so frequent in the region, has become more the exception than the rule, allowing for increasing synchronization in the countries' business cycles. As a corollary, or as a preamble, of this growing interconnection, mutual support seems to have been the undeniable path in foreign affairs followed by political leaders, regardless off their diverse ideological spectrum. Latin America faces new challenges now, from deeper economic integration to macroeconomic coordination, or even a monetary union between some of its countries. Thus, it is important to evaluate the synchronicity in its business cycles, not only from an academic but also from a policy perspective.

The present paper undertakes the goal of measuring business cycles synchronicity in the major Latin American countries. Following Diebold and Yilmaz (DY henceforth), we estimate a rolling-sample vector autoregressive (VAR) model which, conveniently, is invariant to variable ordering. To perform this task, the industrial production indexes (IPI) of Argentina, Brazil, Chile, Colombia, Mexico and Peru are used as proxies of their respective countries' aggregate activity. One of DY methodology's main advantages is that it uses rolling windows and can, therefore, account for time variation in the connectivity. This attribute becomes crucial when the are non-linearities or structural breaks during the analyzed period. In fact, one would expect business cycles' synchronization to be different in times of world expansions from times of contractions, as noted by Camacho and Pérez-Quirós (2008). A second advantage of DY's method is that it provides not only pairwise connectedness indexes, as the bulk of the international business cycles literature does, but also clustered and total connectedness, which delivers a broader picture of the network under study.

Being a reduced-form model, DY's setup requires no *a priori* assumptions other than normality in the errors distributions. As such, no structural (i.e, economically motivated) identification is proposed over the VAR's covariance matrices. Instead, the ultimate goal of the analysis is to verify how strongly (or poorly) connected Latin American business cycles are. Nevertheless, the present work pretends to interpret the results and to suggest possible lines of causality. And, to undertake this more demanding task, the methodology provided by DY is not sufficient.

To overcome this problem, we complement DY's methodology with the filtered IPIs, which have been previously regressed on the US financial conditions index. This indicator is published by the Federal Reserve Board of Chicago and comprehends many variables, ranging from the Fed and Treasury yield rates at different maturities to financial assets. As Canova (2005), among others, found out, Latin America has been typically vulnerable to US financial shocks. Hence, we propose to interpret the residuals of the regression as the countries' idiosyncratic components. Following this interpretation, we then feed DY's model, alternatively, with the actual IPIs and the countries' respective filtered series and compare the connectivity indexes obtained. Consequently, we interpret the differences of connectedness obtained as a common factor. We show that our approach renders a richer interpretation of the results and thus can be more useful in understanding the system connectedness. Actually, as noted by Stock and Watson (2005), the relevance of a common component underlying the business cycles' connectedness is substantial during global recessions. Consequently, any study about the cyclical properties of an interconnected system should take this into account.

In their original contribution, DY plot their connectivity indexes together with the NBER US recession periods and find that connectivity among rich countries generally increase during these episodes. Consequently, for the purpose of our work, it is indispensable to count on an estimation of Latin American recession periods. To obtain it, we estimate a Markov Switching VAR (MS-VAR) model, based on BenSaïda et al. (2018), where the state of the economy is endogenously determined. This model delivers probabilities of of recession (and expansions) which are plotted together with the connectivity indexes. We document five recession periods in Latin America: at the early 1990s, in 1995, during 1998 and 1999, from the end of 2008 to mid-2009 and in 2020. These recessions correspond, respectively, with the hyperinflationary episodes, the Tequila effect, the Asian crisis, the Global Financial crisis and the COVID-19 Great Lockdown.

As in DY, we find that connectedness increases significantly during and in the aftermath of regional crises. However, the discrimination between idiosyncratic and common components helps to interpret the connectedness, which is vital for policy prescriptions. I.e., following Mundell (1961)'s theory of optimal currency areas, appropriate macroeconomic coordination requires a certain region to be affected by common rather than asymmetric shocks[2]. In this sense, our approach can be used to evaluate the potential effects of policy coordination in Latin America. According to our estimates, even if the whole region can benefit from coordination during international crises, the group of countries comprising Argentina and Brazil, on one hand, and Chile, Colombia, Mexico and Peru, on the other hand, are suitable for coordination. This observation applies because the common component tends to be relevant in either group.

The present paper contributes to the literature in four aspects. First, the period of study: by including the last three decades, this article has the advantage of analyzing the period when Latin American regional integration accelerated. The works of Arnaudo and Jacobo (1997) and Loayza et al. (2001) were written when Latin American trade and financial integration was in its early stages and, as such, when it was still too soon to have a reliable picture of connectedness. Furthermore, these first works include the 1980's, which was a decade of tremendous macroeconomic

[2]On the other hand, Alesina and Spolaore (1997) state that a region mostly facing idiosyncratic shocks can be better off under policy coordination because of the potential smoothing role of intraregional transfers.

instability in most of the countries of the region. Amid such unstable outcomes, no synchronized cycles can be expected to arise.

Second, this work can capture the potential dynamic evolution of the business cycles' comovement with the estimation of rolling windows. In fact, total connectedness is expected to increase during international crises (or booms) because countries within the region share similar trade patterns and, as a result, are subject to similar terms of trade shocks. In the same fashion, common financial disturbances, like US monetary policy innovations, more often than not impact all Latin American countries, like when the taper tantrum took place in 2013. Existing works, like Ahmed (2003) and Mejía-Reyes (2004), rely on fixed-coefficients estimations and, hence, cannot account for this expected evolution in Latin American countries' synchronizations.

Third, compared to articles in the literature that account for time-varying bidirectional relations in Latin America (Cerro and Pineda (2002), Aiolfi et al. (2011) and Camacho and Palmieri (2017))), the present article adds total and clustered connectedness. These features of DY's methodology, complemented with the used of filtered series in the estimation of the connectedness indexes, allow for a broader assessment of cyclical synchronization.

Fourth, to our knowledge, there are no previous works that formally address the suitability of policy coordination in Latin America. We provide the first academic work that touches upon an issue that has been in the regional political leaders' agenda many times in the past. So, this paper can also contribute to the discussion of this relevant, though poorly covered, international economy topic.

The rest of the article is organized as follows: section 2 presents some empirical facts that motivated the selection of Latin American business cycles as the paper's main focus. We show that the evolution of the six biggest economies in the region (Argentina, Brazil, Chile, Colombia, Mexico and Peru) display some features since the 1990's which makes it important to evaluate their cyclical synchronization. Section 3 goes briefly through the model and presents the results, organized in the connectedness indexes. We also explain how the MS-VAR model can obtain probabilities of global recessions that turn out to be useful in the subsequent analysis. This section makes particular emphasis on the benefits derived from feeding DY's model alternatively with the original and filtered data to interpret common and idiosyncratic components of business cycles connectedness. It also discusses the policy implications of the results in terms of the macroeconomic coordination viability. Finally, section 4 concludes.

2 Empirical facts

This section provides evidence in favor of a growing interconnection between Latin American countries with data from national sources since the mid 1980's until 2021. Important changes occurred during this time frame. First, regional trade has gained relevance, fostered by trade agreements. Evidence on this is presented in Figure 1. Second, financial links have grown stronger, as shown in Table 1. Third, countries have generally converged from high to low inflation in the 1990's, which, compared to the instability of the 1980s, reflects a macroeconomic moderation. Evidence on this improved outcome is presented in Figure 2. Among the case studies analyzed here, Argentina is probably the exception. However, the macroeconomic misalignments observed in the 2000's and even in the 2010's in this country, are much more subtle than those of the past. Fourth, variations in the nominal exchange rate, which is a key variable to identify macroeconomic instability, became more correlated among countries in the last years, as shown in Table 2. And fifth, once trade and financial links grow stronger and macroeconomic misalignments become less frequent, business cycles can be expected to become more correlated. Evidence on this is presented on Table 3

The evolution of regional trade: Latin American countries joined the world economy as commodity's suppliers and manufactures' buyers. Although this center-periphery trade pattern is still largely present, strong commercial links began to grow among many countries in the region after the 1970's. This has fostered custom unions and trade liberalizations agreements, such as the Mercosur in the early 1990's and the Pacific Alliance in the 2010's. Although these agreements have pitfalls and the countries are still looking for a proper balance in their economic relations, the result was an increasing trade share devoted to regional partners, as shown in Figure 1.

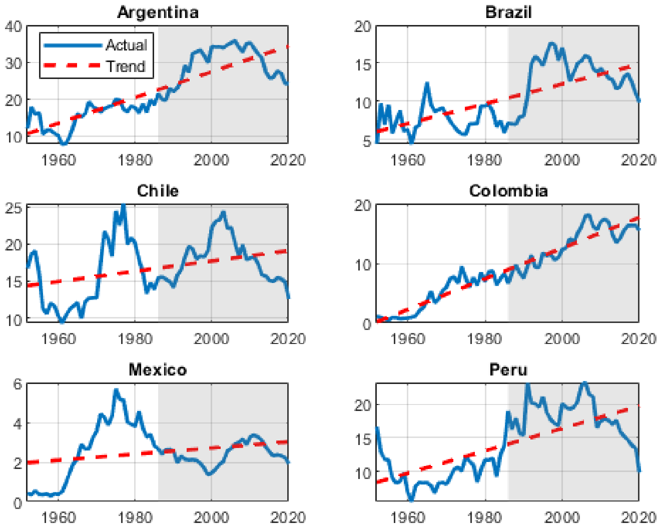
Figure 1 plots the regional trade openness as a share of total trade openness per country:

$$RT_{i,t} = \frac{X_{ij,t} + M_{ij,t}}{X_{i,t} + M_{i,t}} * 100$$

where $RT_{i,t}$ is regional trade as a percentage of total trade of country i at period t; $X_{ij,t}$ are exports from country i to country j at period t; $M_{ij,t}$ are imports of country i from country j at period t; $X_{i,t}$ are total exports of country i and $M_{i,t}$ are its total imports at period t. Countries i and j represent, respectively, each country and the remaining ones of the sample.

The selection of countries is based on their economic relevance, as they are the main economies in the region with the exception of Venezuela, which has been excluded because of lack in official data. Figure 1 shows that regional trade has tended to increase since the 1990's for most countries, reaching shares between 10% and 40% of total trade. The only exception to this is Mexico, where regional trade is rather small when compared with total trade, not surpassing 4% during the analyzed period. Nevertheless, there is a positive, though subtle, trend in regional trade for Mexico.

Fig. 1: More regional trade



Note: The vertical axis represents the regional trade openness as a percentage of total trade openness. The shaded areas represent the years under study. Source: IMF Financial Statistics.

Growing financial links: Financial links have grown stronger since World War II and this process tended to accelerate since the abandonment of Bretton Woods in 1971. In general, developing countries also leaned towards tighter financial integration with the rest of the world.

As for Latin America, financial integration within the region has experienced an important evolution. A representation of this was the creation of the Latin American Integrated Market (Mercado Integrado Latinoamericano -MILA-) in 2010, which consists in the integration between the stocks markets of Chile, Colombia and Peru. Later on, in 2014, Mexico joined the MILA, turning it into the top (joint capitalized) stock exchange in the region. Mellado and Escobari (2015) found evidence suggesting that the MILA has fostered an increase in the correlation of stock returns between these countries. Table 1 shows that correlations in national stock exchange indexes have indeed increased in the last period.

Each cell in Table 1 displays the correlation of the annual variation in the S&P indexes for each pair of countries and the last row shows the mean correlation for each country at every period. These periods broadly represent the high volatility years (which lasted approximately until 1994), the macroeconomic moderation period (1995-2003) and the floating regimes periods (2003-21), which have extended till nowadays. This sub-periods broadly coincide with the implementation of Mercosur in 1994 and the overcoming of the Asian and Turkish crisis, whose effects in Latin America lasted approximately until 2003.

Although stock market data is only available since 1992, and even this information is unbalanced, it is verified that stock markets indexes became more correlated. The exception is Argentina, for which no significant change is observed.

Table 1: Deeper financial integration

	1992-1994						1995-2003						2003-2021					
	Ar	Br	Ch	Co	Me	Pe	Ar	Br	Ch	Co	Me	Pe	Ar	Br	Ch	Co	Me	Pe
Ar	1.0	0.4	0.8	-	-	0.1	1.0	0.3	0.2	-	0.6	0.6	1.0	0.5	0.5	0.3	0.5	0.4
Br	0.4	1.0	0.4	-	-	-0.2	0.3	1.0	0.4	-	0.5	0.5	0.5	1.0	0.7	0.6	0.7	0.8
Ch	0.8	0.4	1.0	-	-	-0.3	0.2	0.4	1.0	-	0.3	0.5	0.5	0.7	1.0	0.6	0.7	0.7
Co	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.6	0.6	1.0	0.7	0.6
Me	-	-	-	-	-	-	0.6	0.5	0.3	-	1.0	0.5	0.5	0.7	0.7	0.7	1.0	0.8
Pe	0.1	-0.2	-0.3	-	-	1.0	0.6	0.5	0.5	-	0.5	1.0	0.4	0.8	0.7	0.6	0.8	1.0
Mean	0.5	0.2	0.3	-	-	-0.1	0.4	0.4	0.4	-	0.5	0.5	0.4	0.7	0.6	0.6	0.7	0.7

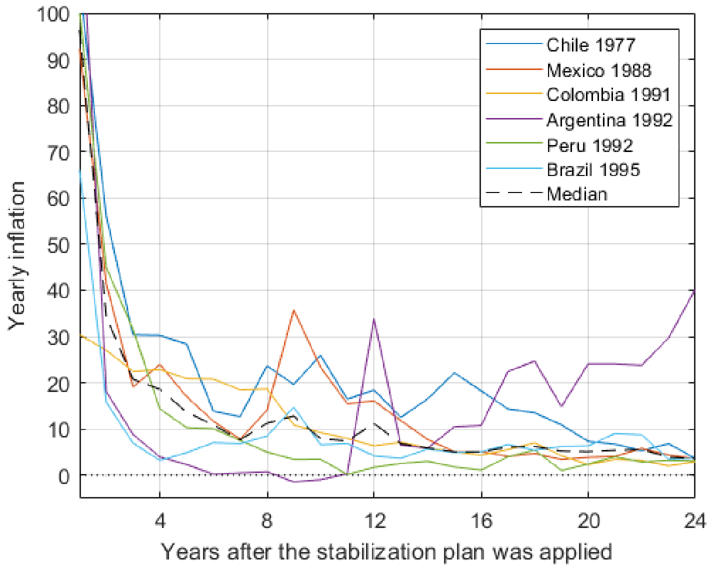
Note: correlation table of yearly variations of the national stock market S&P indexes. Source: Bloomberg.

As for Colombia, it is not possible to evaluate the evolution of the correlation of its national stock index with the rest because there is no data for the two initial periods. However, Colombian correlation with the rest of the countries, but Argentina, is quite significant for the period 2003-21. Which suggests that the aforementioned MILA has indeed worked in deepening the financial integration for this country as well.

Macroeconomic moderation: Another observed characteristic is that Latin American countries have significantly improved their macroeconomic performance. High inflation and recurrent devaluations that were so common in the past, have been, generally, overcome. Hence, it can be argued that the country-specific noise that used to blur the links between countries' business cycles is not as strong as before. And that, as a consequence, countries' comovements must have become more synchronized than before.

Although the region has suffered longly from macroeconomic mismanagement, the stabilization plans have generally been successful in reducing inflation. Figure 2 shows the speed of disinflation after the stabilization programs were applied. Chile implemented a stabilization plan (known as 'The Brick' - *El ladrillo*-) in the mid-1970's and Mexico put into practice the growth and stability pact (Pacto de Estabilidad y Crecimiento Económico -PECE-) in the mid-1980's. As for Peru and Argentina, they applied their stabilization plans in 1992 by changing their currencies denomination: *Sol* for *Inti* in Peru and *Peso* for *Austral* in Argentina. Peru adopted an administrated peg, while Argentina implemented the Convertibility plan with a hard peg. Regarding Brazil, it was the last country that successfully stabilized the economy in 1995 by changing the currency with the *Real Plan*. Colombia was the only country analyzed here which did not undergo hyperinflationary episodes, though the country did experience high inflation until the early 1990s.

Fig. 2: Improved macroeconomic outcome



Source: National Statistics Institutes and Cavallo (2012) for Argentina.

The stabilization programs did finally achieve low inflation rates in the long-run. Nevertheless, as Figure 2 presents, the speed of convergence was not homogeneous. While Chile and Colombia suffered from a stronger persistence in inflation, Mexico, Peru and Brazil could reduce it quite fast and, with the exception of the devaluation occurred in Mexico and Brazil nine years after their stabilization plans were applied, inflation remained below 10% for both countries from then on.

A special mention deserves the case of Argentina. While the Convertibility Plan was very effective in reducing inflation, this has not been the case since the abandonment of the hard peg in 2002. In contrast with the region, the floating regime has come with an increasing inflation that has not been controlled yet. In fact, Campos (2019) shows that Argentina had a more rigid exchange rate policy than the rest of the region during the 2000s, and that this can partly explain its higher inflationary level. However, this level of inflation is still much lower than in the 1980's, at least by the time of writing this paper.

Stronger exchange rate correlations: Table 2 shows that nominal exchange rates' variations have become more correlated in the last decades. As before, the periods broadly represent the hyperinflationary years (1986-1994), the macroeconomic moderation (1994-2003) and the floating regimes period (2003-21).

Table 2: Higher exchange rate correlations

	1986-1994						1994-2003						2003-2021					
	Ar	Br	Ch	Co	Me	Pe	Ar	Br	Ch	Co	Me	Pe	Ar	Br	Ch	Co	Me	Pe
Ar	1.0	0.4	0.0	0.4	-0.1	-	1.0	-0.1	0.1	-0.1	-0.1	-0.3	1.0	0.5	0.5	0.4	0.2	0.5
Br	0.4	1.0	-0.3	-0.3	-0.7	-	-0.1	1.0	-0.1	-0.5	-0.0	0.3	0.5	1.0	0.7	0.8	0.6	0.7
Ch	0.0	-0.3	1.0	0.6	0.4	-	0.1	-0.1	1.0	0.3	-0.7	0.0	0.5	0.7	1.0	0.7	0.6	0.6
Co	0.4	-0.3	0.6	1.0	0.4	-	-0.1	-0.5	0.3	1.0	-0.1	0.2	0.4	0.8	0.7	1.0	0.7	0.8
Me	-0.1	-0.7	0.4	0.4	1.0	-	-0.1	-0.0	-0.7	-0.1	1.0	-0.1	0.2	0.6	0.6	0.7	1.0	0.6
Pe	-	-	-	-	-	-	-0.3	0.3	0.0	0.2	-0.1	1.0	0.5	0.7	0.6	0.8	0.6	1.0
Mean	0.2	-0.2	0.2	0.3	-0.0	-	-0.1	-0.1	-0.1	-0.0	-0.2	0.0	0.4	0.7	0.6	0.7	0.5	0.6

Note: correlation table of yearly variations of the nominal exchange rates. Source: National Central Banks.

The last row of Table 2 indicates an increase in the mean correlation for all countries in the last period. Following on what has been argued when analyzing Figure 2, the evolution of Latin American exchange rates' correlations is very much related to the lack of macroeconomic moderation experimented in the region. Hyperinflation episodes in the 1980's were not always contemporaneous among countries and neither were the stabilization plans of the 1980's and early 1990's. Latter on, there were some strong devaluations, like Mexico in 1994, Brazil in 1999 and Argentina in 2002. Although these episodes consisted on isolated events and were far from the systematic devaluations observed before, they prevented exchange rates from becoming significantly correlated during the 1990s.

It was only in the 2000s that upheavals in the local currencies, so common in the past, become more the exception than the rule. Again, a special mention deserves the devaluation episodes of Argentina in 2014, 2016, 2018 and 2019. Which, with the exception of the 2018 tapper tantrum, were rather idiosyncratic events. However, these devaluations did not prevent its currency from becoming more correlated to those in the rest of the region, when compared with its own past.

The higher exchange rate correlations can serve as a diagnosis in what refers to business cycles comovements. Particularly, one would expect that countries' whose currencies fluctuations are more related to have business cycles that are more synchronized, which leads us to our next, and last, piece of motivating evidence before getting into the connectedness analysis in the following section.

Stronger business cycles correlations In order to get an insight into the business cycles comovements of Latin American countries, we show the correlations of the (HP-filtered) cyclical components of the IPI for the hyperinflationary period (1986-94), the period of macroeconomic moderation (1994-2003) and the flexible exchange rates regimes during the last decades (2003-21).

Although it is mainly descriptive, the Table 3 suggests that business cycles became more correlated in the last years. They were barely correlated in the late 1980's and early 1990s, when hyperinflation and hyperdevaluations seriously harmed the region. Their correlation increased substantially from the mid-1990s, when the successful stabilization plans managed to improve the macroeconomic outcome in the region. And business cycles' correlation increase somewhat at the 2000's, when trade and financial links grew stronger.

Table 3: Stronger business cycles correlations

	1986-1994						1994-2003						2003-2021					
	Ar	Br	Ch	Co	Me	Pe	Ar	Br	Ch	Co	Me	Pe	Ar	Br	Ch	Co	Me	Pe
Ar	1.0	-0.1	0.1	0.0	-0.1	0.1	1.0	0.5	0.2	0.4	0.6	0.4	1.0	0.6	0.4	0.4	0.5	0.4
Br	-0.1	1.0	0.1	0.0	-0.4	0.2	0.5	1.0	0.1	0.2	0.3	0.5	0.6	1.0	0.3	0.3	0.5	0.4
Ch	0.1	0.1	1.0	-0.1	-0.2	-0.4	0.2	0.1	1.0	0.4	-0.1	0.5	0.4	0.3	1.0	0.5	0.5	0.4
Co	0.0	0.0	-0.1	1.0	0.1	0.3	0.4	0.2	0.4	1.0	0.2	0.5	0.4	0.3	0.5	1.0	0.4	0.5
Me	-0.1	-0.4	-0.2	0.1	1.0	-0.3	0.6	0.3	-0.1	0.2	1.0	0.3	0.5	0.5	0.5	0.4	1.0	0.5
Pe	0.1	0.2	-0.4	0.3	-0.3	1.0	0.4	0.5	0.5	0.5	0.3	1.0	0.4	0.4	0.4	0.5	0.5	1.0
Mean	-0.0	-0.0	-0.1	0.1	-0.2	-0.0	0.4	0.3	0.2	0.3	0.3	0.4	0.5	0.4	0.4	0.4	0.5	0.4

Note: correlation table of the cyclical components of the HP-filtered series of IP indexes. Source: National Statistics Institutes.

Even if the evidence of higher business cycles' correlations presented in Table 3 is useful for our posterior analysis, it should be noted here that DY's methodology allows a richer analysis of the interconnection of business cycles than a mere correlation coefficient does. While the correlation coefficient is time-invariant and only between pairs, DY's connectivity index is time-varying and can be calculated for the whole region and for a clustered group of countries as well. The next section describes briefly the models used for a more comprehensive international business cycles analysis, as well as the main results of the present work.

3 Measuring business cycles connectedness in Latin American

The reduced-form VAR model applied in this work implies that the empirical strategy consists on an agnostic approach, as there is no need to impose any identification scheme over the variables' responses. However, we pretend to interpret the results obtained and derive some causality implications supported by the evidence, and this becomes an easier task when including common and idiosyncratic components in the estimation, as shown below. In addition, given that DY use the NBER recession periods in their connectedness figures of rich countries, it is indispensable to have a Latin American recession periods estimation for the purpose of this work.

Considering this, we proceed as follows: first, we estimate a MS-VAR model based on BenSaïda et al. (2018) using the Latin American countries' IPI series to estimate probabilities of recession in the region. Second, we estimate DY's connectivity indexes feeding it, alternatively, with the original IPI indexes and these same variables filtered by the US financial conditions index. More precisely, we estimate filtered series for each country by regressing its IPI series on the US financial conditions index, and interpreting the residuals obtained as the countries' idiosyncratic components. Third, we plot the connectivity indexes estimated with the actual IPIs and the filtered series, and we interpret the difference among them as the common factor driving business cycles' connectedness.

As for the data sample, the reason for including IPI instead of GDP is that the DY's connectivity indexes are estimated with rolling windows, which need a high frequency to obtain minimum reliable estimates. The rolling windows lengths are set to five years, which are the baseline size used by DY. Henceforth, we use the IPI of the main economies in the region (Argentina, Brazil, Chile, Colombia, Mexico and Peru), which are available from their respective National Statistics Institutes since 1985. The variations in IPI are highly correlated with the countries' respective GDP growth rates in the period under study, ranging from 0.7 for the case of Colombia, to 0.8 for Argentina, Brazil, Chile and Peru, and 0.9 for Mexico. So, *a priori*, the IPI seems like a good proxy to study business cycles comovements for these countries. The yearly growth rates of countries' IPIs are plotted below in Figure 4 together with the shaded areas identified as regional crisis, as explained below. Next, we describe the models employed and the results obtained with them.

The Markov switching VAR model. As in BenSaïda et al. (2018), let us consider the following K-state MS-VAR model:

$$y_t|s_t = \mathbf{v}_k + \sum_{i=1}^{p} \Phi_{k,i} y_{t-i} + u_{s_t,t} \tag{1}$$

where y_t includes the yearly variations of the $n \times 1$ countries' IPI series for $t = 1, \ldots, T$; $\mathbf{v}_k$ is an $n \times 1$ regime-dependent vector of intercepts and $\Phi_{k,i}$ are $n \times n$ state-dependent matrices. The vector of residuals permits heteroskedasticity following $u_{s_t,t} = \sum_k \epsilon_t$, where $\epsilon_t \overset{iid}{\sim} \mathbb{N}(0_n, I_n)$. $\sum_k$ is a lower triangular regime-dependent matrix, such that $\Omega_k = \sum_k \sum_k'$.

Let us assume as well that the state s_t is a random variable that can only take natural numbers' values $k = 1, \ldots, K$ and that the probability of s_t being in regime j at time t depends only on its immediate past s_{t-1}, when the regime was i. This is:

$$P(s_t = j|s_{t-1} = i, s_{t-2} = k, \ldots) = P(s_t = j|s_{t-1} = i) = p_{ij}$$

For the case of two regimes, the transition probability matrix becomes:

$$\mathbf{P} = \begin{pmatrix} p & 1-q \\ 1-p & q \end{pmatrix} \tag{2}$$

where p (q) is the probability of being in at time t at a regional expansion (recession) conditional on having been at time $t-1$ at an expansion (recession). These probabilities are then used to obtain the probability of being in a regional recession at time t. In particular, whenever the probability of recession is higher than 50%, the corresponding period will be identified as years of regional crisis.

Although the model allows for regime-dependence in the constants $\mathbf{v}_k$, the coefficients $\Phi_{k,i}$, the covariances Ω_k and the transition matrices, we only allow here for state-switching constants because this is enough for the purpose of this work, i.e., to estimate recession probabilities. Nevertheless, we show in the appendix a detailed description of the estimation where regime dependence is present in all parameters[3].

Regional recession. Obtaining regional recession probabilities' estimation is essential in this work, because business cycles' connectedness tend to increase during global recessions. In fact, DY verify that business cycles' synchronization actually rise during US NBER crisis. Therefore, a similar pattern can be followed by countries in LATAM. To investigate this, we must obtain ourselves a regional recession probability estimation. As a matter of fact, the identification of regional recessions itself can be considered as a secondary contribution of this work. Because the evidence indicates that these recessions have become less frequent and more related to global rather than regional events, as argued below.

Correspondingly, we identify regional crisis whenever the probability of Latin American recession is higher than 50%. As shown with gray bars in Figure 3, there are five periods identified: the first one is between March 1990 and September 1992, coinciding with the last hyperinflationary episodes after the "lost decade" of the 1980s. The second goes from March 1995 to December 1995 and it is concurrent to the Mexican "Tequila" crisis. The third one starts at April 1998 and ends at November 1999, and it is contemporary to the Asian crisis. The fourth one goes from September 2008 to July 2009, during the Global Financial Crisis. And the fifth one starts in March 2020 and ends in August of that same year, being concomitant to the Great Lockdown caused by the COVID-19 pandemic.

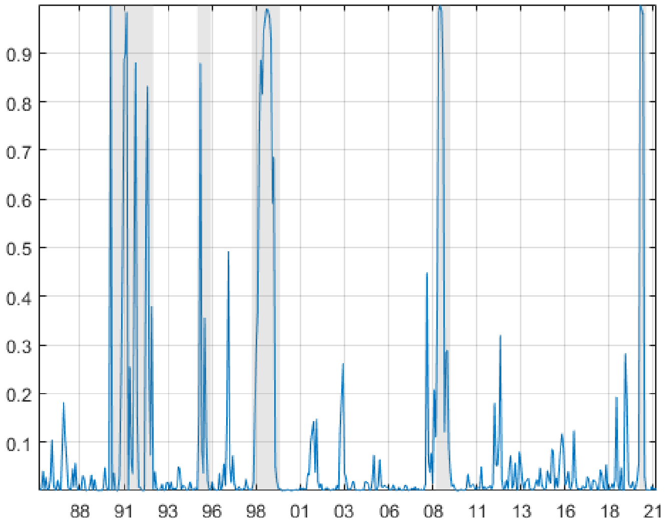
In brief, of the five recessions suffered by Latin America in the last thirty years, three were in the 1990s and only two since the 2000s. Even more, the recessions of the 1990s can be considered mainly regional, as the hyperinflation in the early 1990s and the Mexican crisis in 1995, or of the developing world, as the Asian crisis. On the other hand, the contractions from then on were worldwide events: the Global Financial crisis of 2008 and the Great Lockdown during the COVID-19 in 2020. So, this initial evidence suggests that, in general, Latin America has stabilized substantially in the last two decades. Although countries have suffered idiosyncratic crisis, only those two global events seemed to have affected the region as a whole.

Next, we plot the IPI series of each country together with the regional recession probabilities in Figure 4. This figure shows that the first regional crisis identified, which was contemporaneous to the last hyperinflationary episode, affected almost

[3]The Matlab routines we have programmed have the option to allow for regime-dependence in the desired parameters. These routines are available upon request.

all countries in the region. Hyperinflationary crisis were recurrent in the past and, as described above in Figure 2, it took a while for the stabilization plans applied from the mid-1980s until the early 1990s to balance these economies.

Fig. 3: Regional recession probabilities



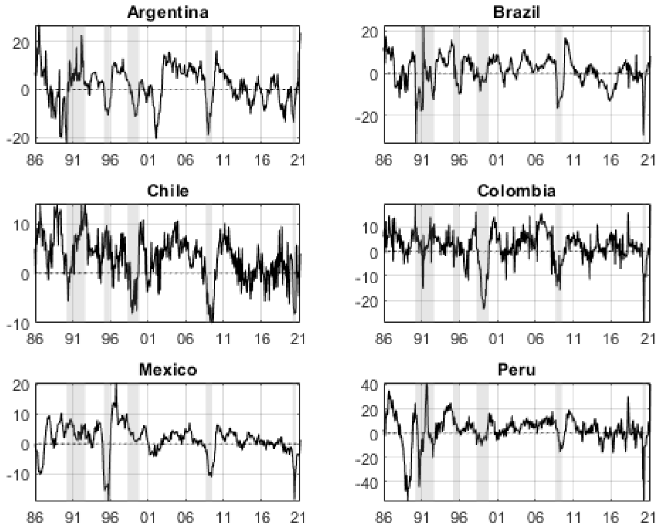
Note: estimates obtained with the MS-VAR model.

The second regional crisis identified, the so-called "Tequila" effect, was the deepest contraction suffered by Mexico until the Great Lockdown during the COVID-19. It also affected significantly Argentina and Brazil and, to a a lesser extent, Colombia. On the other hand, Chile and Peru did not experience contractions during this episode.

As for the third regional recession identified, it coincides with the crisis that began in Southeast Asia in 1997 and spread to Russia and Turkey later on. In Latin America, most countries were affected between 1998 and 1999, as shown in Figure 4. It was during this period that the *Real* devalued in Brazil in 1999, which caused a significant contraction in Argentina, the so-called "Caipirinhia" effect. In 1999, Colombia suffered as well a tremendous financial crisis, which caused a deep recession only paralleled by the Great Lockdown in 2020.

The fourth and fifth recession periods identified coincide with the Global Financial crisis of 2008 and the Great Lockdown caused by the pandemic. All countries display a profound contraction during both episodes, though the effects of the Global Financial crisis seem more persistent when compared to the COVID-19. In fact, by the time of writing this paper, most countries in LATAM, as in the rest of the world, are experiencing a rebound in activity thanks to the ease of Lockdown measures originally implemented to diminish the spread of the virus.

Fig. 4: Industrial production yearly growth rates and regional recessions (▯)



Source: National Statistics Institutes. Note: regional crisis estimated with the MS-VAR model.

Figure 4 shows other contractions that affected some countries, though they do not qualify as regional recessions according to our estimates. One example would be the downturns observed in Argentina, Brazil, Mexico and Peru during the late 1980's, most probably due to the hyperinflationary pressure suffered by these countries during those years. Another is the Argentinean crack of 2001 which caused the sovereign debt default. Yet, another episode is the Brazilian contraction of 2016 during the social unrest and the impeachment of the president Dilma Rouseff.

Next, the connectivity indexes are analyzed and interpreted.

Connectedness measurement. The model used to analyze business cycles' connectedness is the one proposed by Diebold and Yilmaz (2015), which consists in the following reduced-form VAR model:

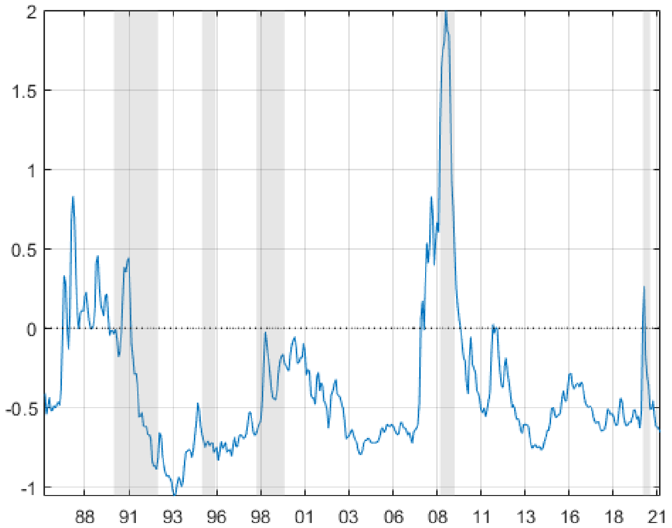
$$\begin{aligned} y_t = A_t(L)\upsilon_t \qquad &; \qquad \upsilon_t \sim \mathcal{N}(0, \Sigma_{\upsilon_t}) \\ A_t(L) = A_{0,t} + A_{1,t} &+ A_{2,t} + \ldots + A_{p,t} \end{aligned} \tag{3}$$

where A represents coefficient's matrices, with L as their corresponding lag operator, p the lag order, υ are the reduced form residuals and Σ_υ their covariance matrix. Notice that matrices A and Σ_υ are time-varying because of the rolling-windows. Another option can be to estimate model (3) with a time-varying coefficients VAR. However, the short sample size can make such estimation unreliable.

From (3), the indexes used to study total, clustered and pairwise connectivity are obtained (see the appendix for details). The main difference of our approach, when compared to DY's original contribution, is that the endogenous vector variables y_t are, alternatively, the yearly growth rates of the countries' IPI and these series filtered by regressing them on the US financial conditions index. As mentioned above, the residuals of these regressions are interpreted as the countries idiosyncratic components. And the difference in the connectedness indexes obtained with the actual IPI and the filtered series are then interpreted as the common factor driving business cycles' connectivity.

The US financial conditions index is a standardized weighted average of more than one hundred financial variables, ranging from US T-bill rates to stocks and risk indicators (Brave and Kelley, 2017). An increase in this index indicates tighter financial conditions, and a decrease in it reflects looser conditions. As displayed in Figure 5, the tightening of US financial conditions broadly coincides with the regional recessions estimated with the MS-VAR model (1).

Fig. 5: US financial conditions index

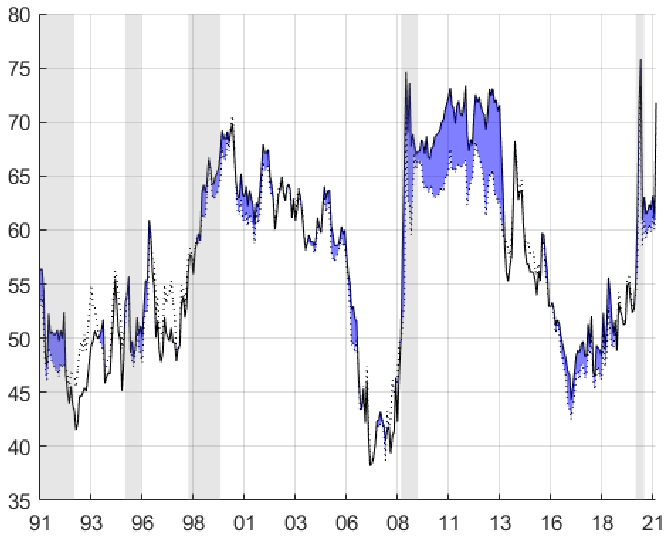


Note: the US financial conditions index is from the Chicago Fed. An increase in this index indicates tighter financial conditions. The gray bars correspond to the regional crisis estimated with the MS-VAR model.

US financial conditions were becoming tighter at the end of the 1980s and the beginning of the 1990s, during the hyperinflationary crisis. In fact, worse US financial conditions are typically identified as the main driver of the Latin American debt crisis back in 1982. These conditions were tense again during the Mexican crisis in 1995 and, specially, during the Global Financial crisis in 2008. The index shows then a relaxation during the Quantitative Easing of the 2010s, until it becomes tighter once more during the Great Lockdown implemented because of the COVID-19 in 2020.

Total connectedness. The DY model provides a total connectedness index which lies between 0 and 100% (see the appendix for details) and is plotted in Figure 6. The solid line is the index's estimate using the actual countries' IPIs and the dotted line was estimated using the filtered series, which are interpreted as the idiosyncratic components. As mentioned above, the difference between them, which is the blue area in Figure 6, can be interpreted as the common factor underlying total synchronicity in the region. It should be noted that, as a consequence of the five-year rolling windows, the connectedness indexes start in 1991 and not 1986, which is the first observation in the sample.

Fig. 6: Total connectedness (%), 5 year rolling window



Note: the solid line was obtained with the IPI and the dotted line with the idiosyncratic components. The blue area indicates the difference among them, which is interpreted as the common factor. The gray bars correspond to the regional crisis estimated with the MS-VAR model.

The evolution of total connectedness the solid line describes in Figure 6 allows to make three main observations: first, total connectedness is quite significant, oscillating between 40% and 80%. This evidence can be interpreted as an important presence of international business cycles in Latin America. In fact, these results are similar to the total connectedness index estimated by DY for G-6 countries from 1958 until 2011. Second, total connectedness varies significantly along time and it increases persistently during regional recessions. Again, this evidence is in line with DY's findings for rich countries' business cycles. Unfortunately, the data is not available to take the estimation earlier back in order to compare how was business cycles connectivity before the regional integration accelerated in the 1990s. However, even in our short sample our findings suggest that connectivity tends to rise, which is consistent with the results presented by Kose et al. (2003). In particular, Kose and coauthors found that there is a common factor driving business cycles' connectivity, which leads us to the observation made next.

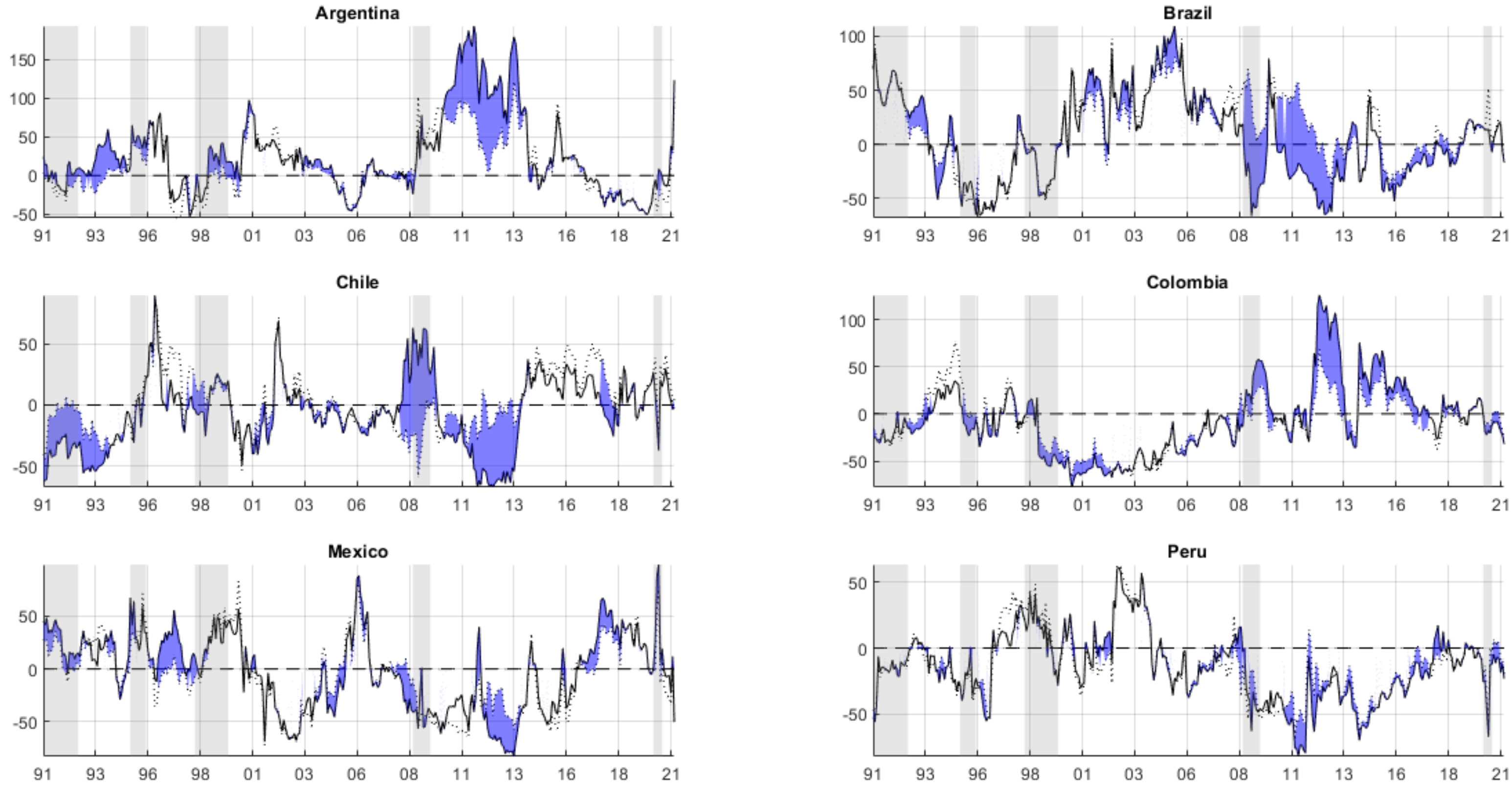
A wider interpretation of the evidence can be made once common and idiosyncratic factors are included into the picture. In fact, it is apparent that business cycles synchronicity gets stronger during and in the aftermath of regional crisis, depicted with gray bars in Figure 6. However, Figure 6 shows that the common component (in blue) increases more in some regional crisis than in others, which suggests that some events were unrelated to the global component, represented here by the US financial conditions. Hence, the nature of the identified regional recession can be related either to a truly Latin American event or to a contraction rather related to the global economy. As it stands, the common component tends to rise when business cycles' synchronicity does during the last hyperinflationary crisis of the early 1990s, the COVID-19 Great Lockdown and, specially, the Global Financial crisis of 2008. However, connectivity during the mid and late 1990s does not display such pattern, which may be due to the fact that these crisis were more of a regional, rather than global nature. As a matter of fact, the Mexican devaluation in 1995 and the Asian crisis in 1997 were mostly causing these regional recessions.

While discrimination between common and idiosyncratic components helps to identify the source of the crisis, the fact that synchronicity rises persistently during regional (or global) recessions has direct policy implications. I.e., the more synchronized business cycles are, the more necessary policy coordination is to mitigate the contagious effects of global or regional shocks.

Leaders in Latin America have longly discussed about policy coordination, and even the idea of a common currency has been several times on the table. The failed Bank of the South, established in 2009 by Argentina, Brazil, Paraguay, Uruguay, Ecuador, Bolivia and Venezuela with promises of initial capital of US$20 billion, could have been the corner stone of such an ambitious plan. However, little has been achieved so far. The only ongoing coordination project in the region is the Latin American Reserves Fund (Fondo Latino Americano de Reservas –FLAR–). The FLAR was created in 1978 and receives contributions from Bolivia, Colombia, Costa Rica, Ecuador, Paraguay, Peru, Uruguay and Venezuela. It serves as a last resort funding alternative to the IMF when current account deficits are persistent or when debt restructuring is needed. Including more countries into FLAR, like the bigger economies of Argentina, Brazil and Mexico, would strengthen its position as lender of last resort and can be a first step towards policy coordination.

Clustered connectedness. This index provides information about the net connectivity given or received by each country. Net clustered (or group) connectedness indexes for each country are plotted in Figure 7. Note that, as described in the appendix, this index can be above 100% (or below -100%) depending on the sum of connectedness given or received by each country at every period. When positive, it implies that the country is giving to the rest of the region more than what it is receiving. When negative, it means that it receives from the rest more than what it is giving. Again, the solid lines were obtained using the original data, while for the dotted lines the idiosyncratic components were used. The difference among them is the common component area in blue.

Fig. 7: Net group connectedness (%), 5 year rolling window



Note: the solid line was obtained with the IPI and the dotted line with the idiosyncratic components. The blue area indicates the difference among them, which is interpreted as the common factor. The gray bars correspond to the regional crisis estimated with the MS-VAR model.

The evidence shown in Figure 7 allows to highlight the advantages of estimating DY model alternatively with the original IPI and the filtered series, interpreted as idiosyncratic components. Not doing so, can lead to imprecise conclusions, because an increase in given connectedness by a particular country can be due to a common, rather than an idiosyncratic component. Consequently, a given country can be assigned more responsibility in affecting other countries business cycles than it actually has. As an example, we might conclude that Chile and Colombia impacted over the rest of the countries during 2008-9 or that Mexico seriously affected the region in 1995, as depicted in the third, fourth and fifth plots of Figure 7, respectively. Nevertheless, these observations can be reinterpreted once idiosyncratic and common components are taken into account. While Mexico's effect over the region was truly idiosyncratic during the so-called "Tequila" effect, Chilean and Colombian impact over the region becomes moderate or null because part or all of the observed effect was actually due to the common component. In fact, as the increase in given connectivity coincides with the Global Financial crisis, it makes sense to consider that it was rather this episode which affected the rest of the countries.

Another remarkable feature in Figure 7 is that, in the aftermath of the Global Financial crisis, connectivity given by Argentina and Colombia and received by Chile, Brazil and Mexico was significant. If discrimination between common and idiosyncratic components were absent, one would be prompted to conclude that the former countries influenced the latter's business cycles somehow. Nevertheless, these rise in connectedness was mostly explained by the common factor. So, once more, this evidence can be reinterpreted considering the circumstances at that time. In fact, the Global Financial crisis spurred the Quantitative Easing era which presumably improved financial conditions in LATAM, causing synchronized boost in aggregate activity.

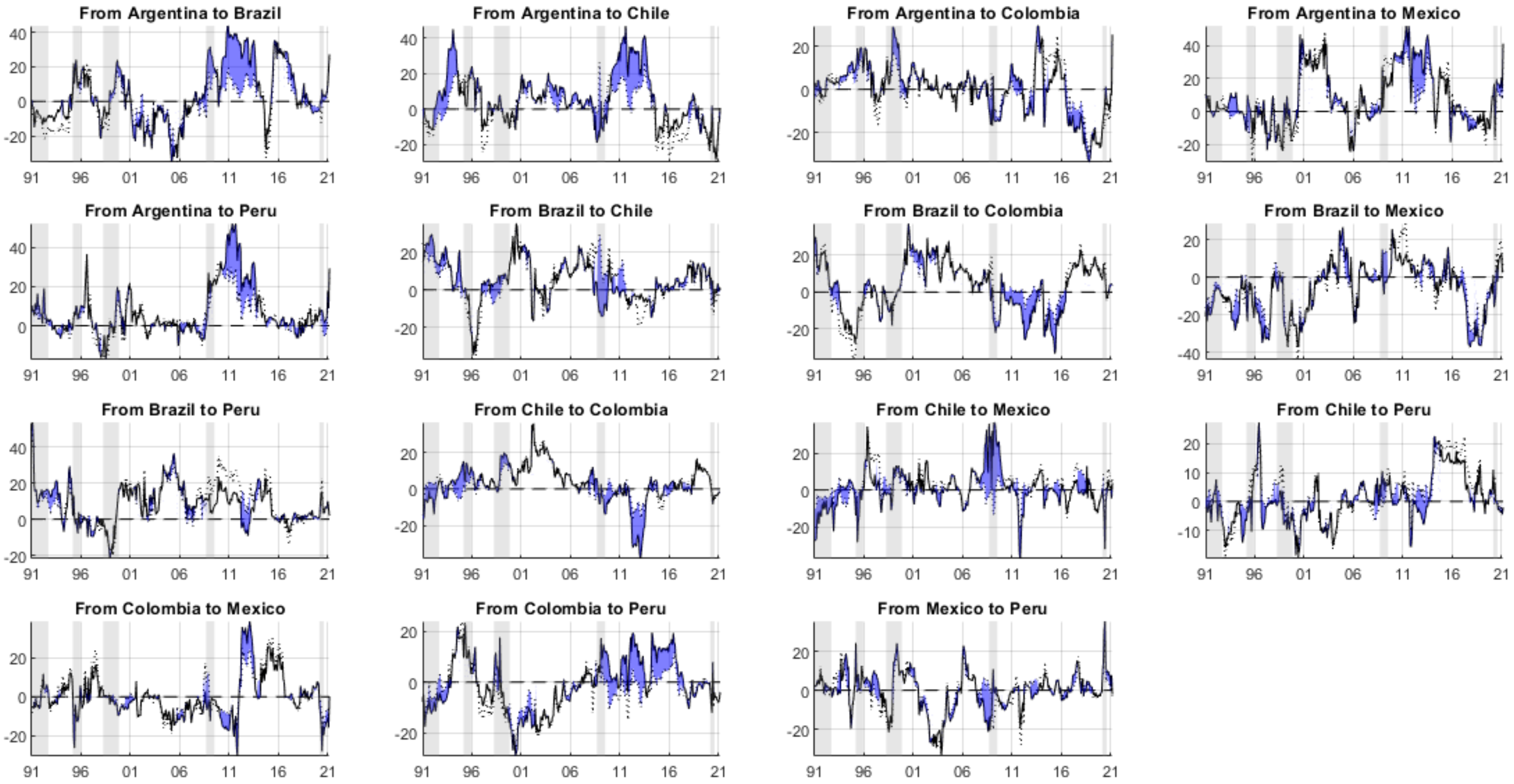
Furthermore, whenever the common component is absent in a plot, this can also help us to interpret the results using some additional information previously known about the analyzed phenomena. For example, the second plot in Figure 7 deploys an increase in connectedness given by Brazil in 2014-5. If only original data were used, it would not be possible to know whether this effect was mostly explained by the common component or if there was anything particular in this country at that time that might have had an impact over the region. As the evidence does not indicate the presence of the common component, it can be concluded that there was rather an idiosyncratic event which affected the rest of countries. In this sense, it can be argued that the political and economic crisis Brazil suffered in 2014 can be held responsible for the increase in connectedness given by this country.

As well, Figure 7 shows that the Argentinean crisis of 2001 affected the rest of the region. This was one of the worse crisis suffered by the country and, according to our results, it was rather an idiosyncratic event, unrelated to the region or the world. In fact, it can be argued that it was rather caused by a self-induced sovereign risk escalation accompanied with rising devaluation expectations (Nocetti, 2006).

Net pairwise connectedness. DY technology provides as well a net pairwise connectedness which consists on the connectivity given from country i to country j, discounting the connectivity received by i from j. Hence, this index can be between -100% and 100% (see the appendix for details).

Figure 8 shows the pairwise net connectedness for all analyzed countries. While a positive effect means that the first country impacts the second, a negative one implies that the reverse is true. Again, the solid lines represent the connectivity index calculated with the actual countries- IPIs, the dotted lines were obtained with the idiosyncratic components and the shaded areas represent the difference among them, i.e, the common factor.

Fig. 8: Net pairwise connectedness (%), 5 year rolling window



Note: the solid line was obtained with the IPI and the dotted line with the idiosyncratic components. The blue area indicates the difference among them, which is interpreted as the common factor. The gray bars correspond to the regional crisis estimated with the MS-VAR model.

Following on the analysis performed when analyzing clustered connectedness above, the evidenced observed in Figure 8 also highlights the usefulness of feeding DY's model alternatively with actual IPI and the filtered series to disentangle between common and idiosyncratic components. As a matter of fact, if only the actual data were used, we might get an unrealistic picture of pairwise connectivity. E.g., we might be tempted to conclude that Argentina affected significantly Brazil during and after the Global Financial Crisis of 2008, as shown in the first subplot, while the rise in connectivity during those years was mostly due to the common component. In contrast, the connectivity between both countries was mostly idiosyncratic in 2015, following the aforementioned Brazilian political-economic crisis. A similar observation can be made with Argentina and Chile, in the second subplot: connectivity between them is driven mainly by the common factor during and in the aftermath of the Global Financial Crisis, though it is mainly idiosyncratic in 2001, when the Argentine domestic crisis hit. Likewise, the connectivity between Colombia and Mexico, shown in the thirteenth subplot, was significantly explained by the common component from 2008 until 2014. But it was mainly idiosyncratic in 1995, during the Mexican Crisis.

When analyzing total connectedness in Figure 6 above, we highlighted that it was desirable to counteract the contagious effects of regional crisis whenever business cycles' synchronicity rosed. This argument can be refined with the evidence presented in Figure 8. Particularly, the inclusion of common and idiosyncratic components can be used here as well to evaluate the suitability of policy coordination.

In the present case, we have assumed that US financial conditions can be interpreted as a common component driving significant comovement in Latin American countries[4]. However, the comovement generated by such exogenous events can be uneven in the region. And it can be useful to know which countries are more exposed to common components, because they might benefit more from policy coordination.

Consequently, the evidence shown in Figure 8 indicates that the following subgroups of countries share a significant common component: Argentina with Brazil and Chile (first and second subplots, respectively), Chile with Colombia and Mexico (tenth and eleventh subplots) and Peru with Colombia and Mexico (fourteenth and fifteenth subplots). So, broadly speaking, two subgroups can be identified: on one hand, Argentina and Brazil (and probably Chile). And, on the other hand, a second subgroup conformed by Chile, Colombia, Mexico and Peru. As these two subgroups share a non-negligible common component, policy coordination can be suitable within them[5].

[4]It can also be argued that commodity or terms of trade shocks are another source driving common business cycles in the region. Yet, there is no consensus of their effect in emerging economies. With a calibrated real business cycle model Mendoza (1995) estimated that they account for the bulk of fluctuations in real activity. On the other hand, Schmitt-Grohé and Uribe (2018) estimates a panel SVAR with emerging and poor countries from 1980 to 2011 and found that terms of trade can only explain around 10% of business cycles in these economies. However, Ben-Zeev et al. (2017) use a SVAR with data from Argentina, Brazil, Chile, Colombia and Peru from 1994 until 2014 where commodity and terms of trade disturbances are augmented with news shocks and found that they contribute to almost half of output variations.

[5]It must be said that there are other insights into this argument. From a political economy perspective, it might be argued that countries sharing a relevant common component in their business cycles can be prone to conflict instead of cooperation (Bazzi and Blattman, 2014).

4 Conclusions

This work studies whether the business cycles of the major Latin American countries are significantly connected. Although international business cycles have been widely analyzed, not much attention has been devoted to emerging nations in general, nor to Latin America in particular. Notwithstanding, the region has undertaken some structural changes in the last decades which make it an interesting case study on this matter. These consisted on an increase in trade and financial integration and a macroeconomic moderation that has been achieved by most of the countries in the region.

The empirical strategy consists on two models: on one hand, we estimate a Markov switching VAR model to identify regional recessions in Latin America from 1990 until 2021. On the other hand, we use the connectivity model developed by Diebold and Yilmaz (2015) to analyze business cycles' synchronization in the region. However, instead of feeding this last model with the Industrial Production Indexes only, as these authors originally do, we use as well these series filtered with the US financial conditions index, which can be assumed to be a common component affecting the region. Consequently, the filtered series can be interpreted as the idiosyncratic components underlaying business cycles' connectedness.

Our results suggest that regional crisis have become less frequent than in the past and that they are more related to global contractions, such as the Global Financial crisis of 2008 and the Great Lockdown during the COVID-19, rather than truly regional events, such as the "Tequila" effect on 1995. In addition, the evidence indicates that business cycles' synchronicity rises persistently during periods of regional recessions, which has important policy implications. In particular, the results imply that macroeconomic coordination is recommendable among countries in the region to cushion the contagious effects of shared economic fluctuations.

Lastly, the pairwise connectedness analysis can help to discriminate among subgroups of countries that can profit from such coordination. According to the estimates, one subgroup conformed by Argentina, Brazil and, to a lesser extent, Chile, can benefit from coordination because they share a non-negligible common component in business cycles' pairwise connectivity. Another subgroup with such characteristics is conformed by Chile, Colombia, Mexico and Peru, which can also find coordination advantageous because connectedness among them is significantly explained by the common factor.

A Appendix

Markov switching VAR model. In the model (1), the transition probability matrix (2) described in the main body of the article with only two regimes can be extended to K states:

$$\mathbf{P} = \begin{pmatrix} p_{11} & p_{21} & \cdots & p_{K1} \\ p_{12} & p_{22} & \cdots & p_{K2} \\ \vdots & \vdots & \ddots & \vdots \\ p_{1K} & p_{2K} & \cdots & p_{KK} \end{pmatrix}$$

We can represent this Markov chain as a vector autoregression: being a random vector whose j-th element is equal to one if $s_t = j$ and to zero in the case of s_t taking any other value. Then,

$$\xi_t = \begin{cases} (1, 0, 0, \ldots, 0)' & \text{if} \quad s_t = 1 \\ (0, 1, 0, \ldots, 0)' & \text{if} \quad s_t = 2 \\ \quad\quad \vdots & \\ (0, 0, 0, \ldots, 1)' & \text{if} \quad s_t = K \end{cases}$$

And, hence,

$$\mathbb{E}(\xi_{t+1}|s_t = 1) = \begin{bmatrix} p_{i1} \\ p_{i2} \\ \vdots \\ p_{iK} \end{bmatrix} \Rightarrow \mathbb{E}(\xi_{t+1}|\xi_t) = P\xi_t \Rightarrow \xi_{t+1} = P\xi_t + \varepsilon_{t+1}$$

The parameters to estimate in this model are the regime-dependent vector of intercepts $\mathbf{v}_k$, the state-dependent matrices $\Phi_{k,i}$, the variance-covariance matrices Ω_k and the transition probabilities matrix P.

For higher than two dimensional VAR models, like the one used here, the number of parameters poses considerable difficulties in obtaining maximum likelihood estimation and converging to local optimum. Henceforth, following Hamilton (1990), we use the iterative expectation-maximization (EM) algorithm, which poses good convergence properties. The steps of the EM algorithm are:

1. *Initialization.* The initial parameters of the first regime are set to the estimated VAR without regime change. For the remaining regimes, the first step parameters are multiplied by a factor to avoid identification problems due to similarity between states.

2. *Expectation step.* For every period t, we generate the inferred probabilities of being in any of the regimes conditional on both the data generated until period t and on the VAR parameters' values for each regime. We can also obtain probabilities' predictions for the period $t + 1$ conditional on the data until period t. To obtain these regime-switching probabilities we iterate through

the following equations:

$$\underbrace{\hat{\xi}_{t|t}}_{K\times 1} = \frac{\eta_t \odot \hat{\xi}_{t|t-1}}{\mathbf{1}'_K(\eta_t \odot \hat{\xi}_{t|t-1})}, \qquad t = 1, 2, \ldots, T$$
$$\hat{\xi}_{t+1|t} = \mathbf{P}\hat{\xi}_{t|t}, \qquad t = 1, 2, \ldots, T$$

where $\odot$ is the Hadamard product (element by element matrix multiplication) and

$$\hat{\xi}_{t|t} = \left(\hat{\xi}_{1,t|t}, \hat{\xi}_{2,t|t}, \ldots, \hat{\xi}_{K,t|t}\right)', \qquad \hat{\xi}_{t+1|t} = \left(\hat{\xi}_{1,t+1|t}, \hat{\xi}_{2,t+1|t}, \ldots, \hat{\xi}_{K,t+1|t}\right)'$$

In addition, the ergodic probabilities $\hat{\xi}_{1,0} = \tilde{\pi}$ are obtained with

$$\underbrace{\tilde{\pi}}_{K\times 1} = (A'A)^{-1}A'e_{K+1}$$

where

$$A = \begin{bmatrix} I_K - \mathbf{P} \\ \mathbf{1}'_K \end{bmatrix},$$

e_{K+1} is the $(K+1)$-th column in I_{K+1} and

$$\underbrace{\eta_t}_{k+1} = \left(\eta_{s_t=1,t}, \eta_{s_t=2,t}, \ldots, \eta_{s_t=K,t}\right)'$$
$$\eta_{s_t=k,t} = (2\pi)^{-n/2}|\Omega_k|^{-1/2}\exp\left[-\frac{1}{2}u'_{s_t=k,t}\Omega_k^{-1}u_{s_t=k,t}\right]$$
$$\underbrace{u'_{s_t=k,t}}_{n\times 1} = y_{s_t=k,t} - \mathbf{v}_k - \sum_{i=1}^{p}\Phi_{k,i}y_{t-1}$$

As well, using the algorithm of Kim (1994), we obtain the smoothed probability vector:

$$\underbrace{\hat{\xi}_{t|T}}_{K\times 1} = \hat{\xi}_{t|t} \odot \left[\mathbf{P}'\left(\hat{\xi}_{t+1|T} \oslash \hat{\xi}_{t+1|t}\right)\right], \qquad t = T-1, T-2, \ldots, 1$$

where $\oslash$ represents the element by element matrix division.

3. *Maximization step.* First, we need to estimate the transition matrix of the Markov chain $\mathbf{P}$ as a vector of order (K^2+1). This is:

$$\text{vec}(\hat{\mathbf{P}}') = \underbrace{\hat{\xi}^{(2)}}_{K^2\times 1} \oslash \left(\underbrace{\mathbf{1}_K}_{K\times 1} \otimes \underbrace{\hat{\xi}^{(1)}}_{K\times 1}\right)$$

where $\otimes$ is the Kronecker product and

$$\hat{\xi}^{(2)} = \sum_{t=1}^{T-1} \hat{\xi}^{(2)}_{t/T}$$

$$\hat{\xi}^{(2)}_{t/T} = \underbrace{\text{vec}(\hat{\mathbf{P}}')}_{\text{from previous iteration}} \odot \underbrace{\left[\left(\underbrace{\hat{\xi}_{t+1|T}}_{K\times 1} \oslash \hat{\xi}_{t+1|t}\right) \otimes \hat{\xi}_{t|t}\right]}_{K^2\times 1}$$

$$\underbrace{\hat{\xi}^{(1)}}_{K\times 1} = \underbrace{\left(\underbrace{\mathbf{1}'_K}_{1\times K} \otimes I_K\right)}_{K\times K^2} \underbrace{\hat{\xi}^{(2)}}_{K^2\times 1}$$

Second, we estimate the parameters matrix $\Theta = \theta_1, \theta_2, \ldots, \theta_K$ for all regimes with generalized linear squares (GLS) in each iteration, assuming the following order for each θ_k:

$$\theta_k = \text{vec}\begin{bmatrix} \mathbf{v}'_k \\ \Phi'_{k,1} \\ \vdots \\ \Phi'_{k,p} \end{bmatrix}$$

In the j-th iteration, the estimation will be as follows:

$$\underbrace{\hat{\theta}^{(j)}_k}_{nR\times 1} = \underbrace{\left[\underbrace{I_k}_{n\times n} \otimes \underbrace{\left(X'_k \hat{\Gamma}^{(j)}_k X_k\right)^{-1} X'_k \hat{\Gamma}^{(j)}_k}_{R\times T}\right]}_{nR\times nT} \underbrace{\mathbf{y}}_{nT\times 1} \quad , \qquad R = np + 1$$

where

$$\underbrace{X_k}_{T\times R} = (\underbrace{\mathbf{1}_T}_{T\times 1}, \underbrace{\mathbf{y}_{t-1}}_{T\times n}, \ldots, \underbrace{\mathbf{y}_{t-p}}_{T\times n}), \qquad \underbrace{\mathbf{y}}_{nT\times 1} = (\underbrace{\mathbf{y}'_1}_{T\times 1}, \underbrace{\mathbf{y}'_2}_{T\times 1}, \ldots, \underbrace{\mathbf{y}'_n}_{T\times 1})'$$

$$\underbrace{\hat{\Gamma}^{(j)}_k}_{T\times T} = \text{diag}(\underbrace{\hat{\xi}^{(j)}_{k,t|T}}_{T\times 1}), \qquad \underbrace{\hat{\xi}^{(j)}_{t|T}}_{T\times K} = \left(\hat{\xi}^{(j)}_{1,t|T}, \hat{\xi}^{(j)}_{2,t|T}, \ldots, \hat{\xi}^{(j)}_{K,t|T}\right), \qquad \underbrace{\hat{\xi}^{(j)}_{k,t|T}}_{T\times 1} = \left(\hat{\xi}^{(j)}_{k,1|T}, \hat{\xi}^{(j)}_{k,2|T}, \ldots, \hat{\xi}^{(j)}_{k,T|T}\right)'$$

$$\underbrace{\hat{\Omega}^{(j)}_k}_{n\times n} = \frac{1}{\hat{T}^{(j)}_k} \left(\hat{u}^{(j)}_k\right)' \hat{\Gamma}^{(j)}_k \underbrace{\hat{u}^{(j)}_k}_{T\times n}, \qquad \hat{T}^{(j)}_k = \sum_{t=1}^{T} \hat{\xi}^{(j)}_{k,t|T}$$

$$\hat{u}^{(j)}_k = \mathbf{y}^{(r)} - X_k \hat{\theta}^{(j),(r)}_k, \qquad \mathbf{y}^{(r)} = \text{reshape}(\mathbf{y}, T, n), \qquad \hat{\theta}^{(j),(r)}_k = \text{reshape}(\hat{\theta}^{(j)}_k, R, n)$$

4. *Stop criteria.* The log-likelihood function is:

$$\begin{aligned}\ln L &= \sum_{t=1}^{T} \ln f(y_t|y_{t-1}) \\ &= \sum_{t=1}^{T} \ln(\hat{\eta}_t' \hat{\xi}_{t|t-1})\end{aligned}$$

And the convergence criteria is:

$$\text{i)} \qquad \Delta_1 = \frac{\ln L\left(\hat{\Theta}^{(j+1)}\right) - \ln L\left(\hat{\Theta}^{(j)}\right)}{\ln L\left(\hat{\Theta}^{(j)}\right)}$$

$$\text{ii)} \qquad \Delta_2 = \parallel \hat{\Theta}^{(j+1)} - \hat{\Theta}^{(j)} \parallel$$

The algorithm will end when these two criteria are jointly lower than 10^{-5}. Otherwise, the algorithm will go back to step 2.

As mentioned in the main body of the article, we only allow for regime-dependence in the constant vector because this is enough to estimate recession probabilities. In this case, when we update the matrices $\Phi_k, k = 1, 2, \ldots, K$ and the matrices $\Omega_k, k = 1, 2, \ldots, K$, these will be collapsed into a single matrix averaging with the ergodic probabilities estimated in each iteration. This is, in the i-th iteration, we will have:

$$\hat{\Phi}^{(i)} = \sum_{k=1}^{K} \tilde{\pi}_k \hat{\Phi}_k^{(i)}, \qquad \hat{\Omega}^{(i)} = \sum_{k=1}^{K} \tilde{\pi}_k \hat{\Omega}_k^{(i)}$$

Diebold & Yilmaz's connectedness measurement. From (3), the generalized variance decomposition (GVD) of country i explained by country j in the prediction horizon h is obtained with:

$$\delta_{ij} = \frac{o_{jj}^{-1} \sum_{h=0}^{H-1} \left(e_i' A_h \Sigma_v e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_i' A_h \Sigma_v A_h' e_i\right)}$$

where o_{jj} refers to each element within the non-orthogonal variance-covariance matrix Σ_v and e is an auxiliary vector with unitary value in the desired position and zeros in the remaining ones. The standardization of the GVD matrix is done with:

$$\tilde{\delta}_{ij} = \frac{\delta_{ij}}{\sum_{j=1}^{N} \delta_{ij}}$$

such that the connectivity index is between 0 and 100%. This index is to be used to verify connectedness among each pair of countries.

At the same time, the net directional connectedness among a pair of countries can be obtained with:

$$C_{ij} = \tilde{\delta}_{ji} - \tilde{\delta}_{ij}$$

where $\tilde{\delta}_{ji}$ indicates the effect of country i to country j, and $\tilde{\delta}_{ij}$ that of country i from country j.

In addition, it is obtained the clustered connectedness received by each country i from the sum of the rest (j):

$$\sum_{j=1,\, j\neq i}^{N} \tilde{\delta}_{ij}$$

as well as the clustered connectedness given by each country i to the sum of the rest (j):

$$\sum_{i=1,\, i\neq j}^{N} \tilde{\delta}_{ji}$$

and the net clustered connectedness of each country i:

$$\sum_{j=1,\, j\neq i}^{N} \tilde{\delta}_{ij} - \sum_{i=1,\, i\neq j}^{N} \tilde{\delta}_{ji}$$

Finally, total connectedness of the system is calculated with:

$$C = \frac{1}{N} \sum_{i,j=1,\, i\neq j}^{N} \tilde{\delta}_{ij}$$

Data. The data used for estimating models (1) and (3), as well as the business cycles correlations of Table 3, are the yearly variations in the monthly IP Indexes of Argentina, Brazil, Chile, Colombia, Mexico and Peru from January 1986 until March 2021. The data sources are their respective National Statistics Institutes. Whenever the indexes are not seasonally adjusted, this adjustment is performed with X-13ARIMA-SEATS from the US Census Bureau. Before proceeding with the estimation, following Stock and Watson (2002), outliers are identified as observations that differ from the sample median by more than six times the sample interquartile range. We replace these observations with interpolated values using the median value of the six adjacent values.

Figure 1 is plotted using yearly data on countries' exports and imports obtained from the IMF Financial Statistics from 1952 until 2020.

The S&P stock data used to calculate the correlations in Table 1 consists on the countries' respective yearly variations in the national market indexes which are the MERVAL (Argentina), IBOV (Brazil), IGPA (Chile), COLCAP (Colombia), MEXBOL (Mexico) and SPBLPGPT (Peru). This data is in monthly frequency and goes from February 1992 until May 2021 for Argentina, Brazil, Chile and Peru. For Mexico it is available since January 1995 and, for Colombia, only since July 2003.

For Figure 2, yearly inflation was calculated using the CPI's in quarterly frequency from each countries' National Statistics Institutes. The exception is Argentina, for which we used the CPI provided by Cavallo (2012) for the period 2007-15, because official inflation is known to have been underestimated during those years. Data samples used are: Argentina (1992-2015), Brazil (1995-2018), Chile (1977-2000), Colombia (1991-2014), Mexico (1988-2011) and Peru (1992-2015).

The correlations coefficients in Table 2 were obtained with yearly variations in the nominal exchange rates available at the countries' respective Central Banks in monthly frequency. Although this data goes from January 1986 until March 2021 for most countries, it only starts in January 1993 for Peru. Henceforth, this is when the sample used in this work starts.

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