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Keywords: Pollution; monetary policy; international linkages.

JEL Codes: E52, E43, Q50.

Does monetary policy impact CO_2 Emissions?

A GVAR analysis

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Abstract

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The data supporting the findings of this study are available from the corresponding author upon reasonable request.

1. Introduction

This paper addresses an important problem, whether monetary policy can affect the environment. Intuitively it can. Using a basic textbook macro model, a contractionary monetary policy reduces aggregate demand, leading the economy to an output level below that of full employment. Assuming a positive relationship between output and CO_2 emissions, the smaller output is associated with a lower pollution level. However, this effect is short-lived as output (and therefore emissions) returns to its long-run level.

Our contribution in this paper is twofold. First, we present a simple model to understand the short and long-run macroeconomic implications of monetary policy to the environment. Second, we estimate the effect of changes in the policy rate using multiple countries. Our method explicitly models their interplay, so that we can assess not only the domestic impact of a policy shift, but also its repercussion to other economies.

Specifically, we use a stylized dynamic AD-AS model to show how monetary policy can reduce CO_2 emissions in the short and long run. We make two assumptions to modify the AD-AS model: 1) the economy is engaged in globalization through global value chains (GVC), which impact trade balance and, consequently, the dynamic aggregate demand, and 2) global emissions of CO_2 are associated with these GVC.

In the empirical part, we use the Global Vector AutoRegressive (GVAR) methodology to evaluate the impact of monetary policy on CO_2 emissions. This method interconnects regions using an explicit economic integration variable (in our case, bilateral trade), allowing for spillover effects. In particular, we can assess how domestic and external adjustments affect the final result of shocks.

We analyze monetary shocks in four economies – the U.S., the U.K., the Eurozone, and Japan – and how they impact CO_2 emissions. We also use data on 8 other countries to build the international economy. The sample covers the period between 1990M1 and 2018M12.

We find that monetary policy affects emissions both in the short- and in the long-run. Generalized impulse response functions indicate that, in reaction to a monetary contraction, CO_2 emissions follow a decreasing path in all regions except the U.K., for which results were statistically insignificant. Furthermore, cointegration analysis suggests a relationship between interest rates and emissions *in the long run*.

The effect of monetary policy is basically domestic since cross-region impulse responses were indistinguishable from zero in most cases. This does not mean that the international economy is irrelevant to explain CO_2 emissions in the analyzed economies. Actually, variance decompositions show that a large fraction (between 18 and 38%) of the fluctuations in emissions come from external sources.

Climate change has received growing attention from researchers due to gloomy predictions about the planet in the subsequent years (Stern et al., 1996; Collins et al., 2012). One branch of this discussion suggests a more active role from governments (Terra, 1995; Clark, 1996; Kahn et al., 2021; Arcila and Baker, 2022; Xu et al., 2022). According to Faria (1998), Rausch (2013), and Chen et al. (2021), monetary and fiscal policies can contribute to mitigating or exacerbating environmental problems. Empirical studies have argued that these policies indeed present real effects on the environment (Halkos and Paizanos, 2016; Wei and Xie, 2020).

Concerning the monetary sphere, Eichenbaum and Evans (1995) and Dees et al. (2007) show that monetary policy has significant spillovers in the financial as well as in the real sectors of economies. In particular, the actions of a country, like the U.S., are not restricted only to its borders. Wei and Xie (2020) build a model that exposes how monetary policy changes global supply chains, and Gertler and Karadi (2015) and Bruno et al. (2018) exhibit other consequences of the monetary policy, such as its effect on the credit cost and financial markets.

Investigating the U.S., Liguo et al. (2022) found that expansionary monetary policy harms the environment, increasing CO_2 emissions. Chishti et al. (2021) undertook a similar analysis using a set of emerging countries (BRICS) and concluded that the Central Bank's actions impact carbon emissions. These studies suggest monetary policy as a relevant tool to help reduce gas emissions.

More recently, Faria, McAdam and Viscolani (2022) developed a Sidrauski model augmented with environmental capital and evaluated equilibrium solutions through the "Green Golden Rule" (Beltratt et al., 1994; Chichilnisky et al., 1995; Faria and McAdam, 2018). They show that, in general, monetary policy is neutral with respect to the environment. Only under a non-balanced budget, when deficits are monetized, is money environmentally non-neutral.

Our paper contributes to this literature in two main aspects. First, we use data from multiple countries to characterize the international economy and understand spillover effects through bilateral trade. Consequently, we incorporate economic integration explicitly in the investigation. In other words, we treat each region as an open economy, which approaches the model to reality - especially because CO_2 emissions are characterized as having negative externalities (Felder and Schleiniger, 2002; Leroutier and Quirion, 2022). The GVAR methodology manages to aggregate this point.

Second, we study the monetary policy of four relevant world economies, the U.S., the U.K., the Eurozone, and Japan, both in the short- and the long-run. This analysis becomes richer when we remember that we connect each region using bilateral trade. Hence, taking the U.S, as an example, a positive shock in the Fed's monetary policy may cause adjustments in the whole system, including the carbon emissions of the other regions. Thus, our approach considers the U.S.'s own dynamics as well as the responses of the other economies. Furthermore, the analysis of four distinct regions allows us to verify and compare how domestic markets react to the same policy (Kounetas, 2018).

The paper is structured as follows. The next section presents the theoretical model. Section 3 describes the GVAR methodology and the data. Econometric results appear in section 4, and the concluding remarks are in Section 5.

2. The Analytical Framework

We consider a simple extension of the dynamic AS-AD model with Global Value Chains (GVC), which are associated with CO2 emissions. We first describe the short-run equilibrium and show how changes in monetary policy affect economic activity and, consequently, emissions. We then look at the long-run equilibrium.

2.1 The Short Run Equilibrium

The subscript t indicates time. Total output depends on domestic and foreign absorption:

$$Y_t = \bar{y} + NX(s_t, \bar{n}) \quad (1)$$

Where Y is total output, NX is net trade balance, which depends on GVC (Bruno et al., 2018; Kim and Park, 2018), $\bar{n}$ is the length of the supply chain, s is the number of production stages that are offshored, $\bar{y}$ is the (closed) domestic output, i.e., the output without the rest of the World (the bar over a variable denotes it is constant).

Total emissions of CO2, denoted by E, depend on total output. Therefore, they depend on the length of the supply chain and how many production stages multinational firms decide to offshore:

$$E_t = \beta\bar{y} + (1-\beta)NX(s_t, \bar{n}) \quad (2)$$

Note that in (2) the pollution impact of domestic absorption is different from net trade balance. We interpret β as a policy parameter by which a government can incentive (or curb) offshoring, thus shifting part of emissions to (or from) other economies. If β is reduced the government aims at exporting emissions to the rest of the world.

The following equations are the demand for goods and services, the Fisher equation, the Phillips curve, adaptive expectations, and the monetary policy rule, respectively:

$$Y_t = \bar{Y} - \alpha(r_t - \rho) + \varepsilon_t \quad (3)$$

$$r_t = i_t - E_t\pi_{t+1} \quad (4)$$

$$\pi_t = E_{t-1}\pi_t + \varphi(Y_t - \bar{Y}) + v_t \quad (5)$$

$$\pi_t = E_t\pi_{t+1} \quad (6)$$

$$i_t = \pi_t + \rho + \theta_\pi(\pi_t - \pi_t^*) + \theta_y(Y_t - \bar{Y}) + u_t \quad (7)$$

where $\bar{Y}$ is the natural level of output, α is the responsiveness of the demand for goods and services to the real interest rate r, ρ is the marginal efficiency of capital, i is the nominal interest rate, π_t is the inflation rate, $E_t\pi_{t+1}$ is the expected inflation rate, π_t^* is the Central Bank's target inflation rate, υ and ε are, respectively, supply and demand shocks. Moreover, θ_π is the responsiveness of the Central Bank to inflation, and θ_y is the responsiveness of the Central Bank to output. Importantly, u_t is a pure monetary shock, with a positive (negative) value indicating a monetary contraction (expansion).

The adaptative expectations assumption implies that the Fischer equation can be written as $r_t = i_t - \pi_t$. Substituting this into equation (7), we have that:

$$r_t - \rho = \theta_\pi(\pi_t - \pi_t^*) + \theta_y(Y_t - \bar{Y}) + u_t \qquad (8)$$

By combining (5) and (6), the Phillips curve can be expressed as:

$$\pi_t - E_{t-1}\pi_t = \pi_t - \pi_{t-1} = \varphi(Y_t - \bar{Y}) + v_t \quad (9)$$

From (8) and (9), it follows that:

$$r_t - \rho = \theta_\pi[\pi_{t-1} + \varphi(Y_t - \bar{Y}) + v_t] + \theta_y(Y_t - \bar{Y}) + u_t$$

$$= \theta_\pi[\pi_{t-1} + v_t] + u_t + \left(\varphi\theta_\pi + \theta_y\right)(Y_t - \bar{Y}) \qquad (10)$$

Finally, by plugging (10) into (3), we can express the short-run equilibrium output as a function of shocks, parameters, and past inflation:

$$Y_t - \bar{Y} = -\alpha\left\{\theta_\pi[\pi_{t-1} + v_t] + u_t + \left(\varphi\theta_\pi + \theta_y\right)(Y_t - \bar{Y})\right\} + \varepsilon_t$$

$$Y_t = \bar{Y} - \frac{\alpha}{1+\alpha\left[(1+\varphi)\theta_\pi + \theta_y\right]}\left[\theta_\pi(\pi_{t-1} + v_t) + u_t\right] + \frac{1}{1+\alpha\left[(1+\varphi)\theta_\pi + \theta_y\right]}\varepsilon_t \quad (11)$$

Equation (11) illustrates two channels through which monetary policy affects economic activity in the short run. The first is basically exogenous and relates to the monetary shock u_t. Specifically, an exogenous monetary contraction ($u_t > 0$) is associated with lower output. We can also see a second channel, which shows the endogenous reaction of the Central Bank to past inflation. A high π_{t-1} is carried through the current period because of the adaptative expectations assumption, which leads the monetary authority to raise interest rates and sacrifice output.

We now connect this effect in economic activity to CO2 emissions. Given Y_t, we find s_t through Eq. (1):

$$NX(s_t, \bar{n}) = \bar{Y} - \frac{\alpha[\theta_\pi(\pi_{t-1}+v_t)+u_t]-\varepsilon_t}{1+\alpha[(1+\varphi)\theta_\pi+\theta_y]} - \bar{y} \quad (12)$$

Finally, given s_t we solve for E_t:

$$E_t = \beta\bar{y} + (1-\beta)\left[\bar{Y} - \frac{\alpha[\theta_\pi(\pi_{t-1}+v_t)+u_t]-\varepsilon_t}{1+\alpha[(1+\varphi)\theta_\pi+\theta_y]} - \bar{y}\right] \quad (13)$$

Equation (13) shows how a monetary contraction – either through an exogenous interest rate hike ($u_t > 0$) or through the endogenous reaction of the Central Bank to high past inflation – leads to *lower* CO2 emissions in the short run. This is in accordance with our previous assessment: any contractionary monetary policy cools off the economy and reduces pollution!

2.2 The Long Run Equilibrium

The long run equilibrium is given by the steady state of the system (3)-(7):

$$\pi_t = \pi_t^* = \pi^* \; (10)$$

$$Y_t = \bar{Y} \; (11)$$

$$i = \pi^* + \rho \; (12)$$

$$r = \rho \; (13)$$

From (11) and (1) we derive the long-run equilibrium value of s:

$$\bar{Y} = \bar{y} + NX(s, \bar{n}) \quad (14)$$

Finally, from (14) and (2), we derive the long-run equilibrium value of the CO2 emissions:

$$E = (1+2\beta)\bar{y} + (1-\beta)\bar{Y} \quad (15)$$

Equation (15) shows the limitations of the monetary policy to affect the environment in the long run. It suggests that, in this model, there is only one way for the monetary policy to impact the emission of CO2 in the long run. It should be through β, the policy parameter by which a government can incentive (or curb) offshoring, thus shifting part of emissions to (or from) other economies.

Assume the government can make β the channel through which monetary policy can act. In this case, it acts through domestic versus external absorption, either as a function of inflation, and/or as a function of the nominal interest rate, $\beta(\pi^*, i)$. As a consequence, no matter how β is affected by these monetary policy variables (either positive or negative), we have:

$$\frac{dE}{d\pi^*} = (2\bar{y} - \bar{Y})\frac{d\beta}{d\pi^*} \lesseqgtr 0 \leftrightarrow 2\bar{y} \lesseqgtr \bar{Y} = \bar{y} + NX(s, \bar{n}) \leftrightarrow \bar{y} \lesseqgtr NX(s, \bar{n}) \quad (16)$$

Or,

$$\frac{dE}{di} = (2\bar{y} - \bar{Y})\frac{d\beta}{di} \lesseqgtr 0 \leftrightarrow \bar{y} \lesseqgtr NX(s, \bar{n}) \quad (17)$$

As shown in (16) and (17), the role of monetary policy is ambiguous, it can either be positive or negative in the long run. Therefore, this remains a typical empirical issue. The following section deals with it.

3. GVAR and Data

The GVAR is a model in which regions are connected (in our case, by bilateral trade). We use domestic variables weighted by trade to build proxies for the international environment. We call these proxies for foreign variables x_{it}^*. Equation (18) portrays a VARX (1,1). The first term is the vector of domestic variables, x_{it}, where the subscripts i

and t stand for regions ($i = 0, \ldots, N$) and time ($t = 1, \ldots T$). The value $i = 0$ denotes the reference region (the U.S.). The right-hand side of the equation has the constant, a_{i0}, the trend, $a_{i1}t$, the vector of lagged domestic variables, $x_{i,t-1}$, vectors of foreign variables in periods t and $t-1$, x_{it}^* and $x_{i,t-1}^*$, and the vector of idiosyncratic shocks, ε_{it}.

$$x_{it} = a_{i0} + a_{i1}t + \Phi_i x_{i,t-1} + \Lambda_{i0} x_{it}^* + \Lambda_{i1} x_{i,t-1}^* + \varepsilon_{it} \qquad (18)$$

Equation (19) describes how we construct the foreign variables. The vulnerability of region i to region j varies according to the share of bilateral trade between them (w_{ij}).

$$x_{it}^* = \sum_{j=0}^{N} w_{ij}\, x_{jt} \qquad (19)$$

We model the GVAR following the idea that monetary shocks spread to the system through long-term interest rates and stock markets. In the present framework, we represent this characteristic by including the foreign long-term interest rate and foreign stock market value in the vector of foreign variables. Formally:

$$x_{it} = (s_{it}, l_{it}, q_{it}, gcf_{it}, \pi_{it}, co2_{it})'$$
$$x_{it}^* = (l_{it}^*, q_{it}^*)' \qquad (20)$$

In equation (20), s_{it}, l_{it}, q_{it}, gcf_{it}, π_{it}, and $co2_{it}$ denote, respectively, the short-term interest rate, long-term interest rate, stock market value, gross capital formation (investment), price level, and CO2 emissions. All variables are in logs. Notice that only l_{it}^* and q_{it}^* are in the vector of foreign variables.

We include the domestic variables listed in equation (20) for all regions, except for CO2 emissions. Particularly, for stability's sake, $co2_{it}$ is incorporated only in the VARX of regions of interest: U.S., Japan, the Eurozone, and U.K. (further details ahead). Furthermore, Pesaran et al. (2004) and Dees et al. (2007) recommend parsimony when including foreign variables in the equations that describe relevant economies, such as the U.S. Therefore, uniquely to the U.S., we opted for including in its VARX only the long-term interest rate as a foreign variable.

As mentioned, variables are in logs. They were transformed according to equation (21), where S_{it}, L_{it}, Q_{it}, CPI_{it}, GCF_{it} and $CO2_{it}$ are the untransformed versions of the short-term interest rate, the long-term interest rate, stock market value, price level, gross capital formation, and CO2 emissions.

$$s_{it} = \frac{1}{12}\log\left(1+\frac{S_{it}}{100}\right), l_{it} = \frac{1}{12}\log\left(1+\frac{L_{it}}{100}\right), q_{it} = \log\left(\frac{Q_{it}}{CPI_{it}}\right), gcf_{it} = \log(GCF_{it}), \quad (21)$$

$$\pi_{it} = \log(CPI_{it}), co2_{it} = \log(CO2_{it}).$$

We divide interest rates by the data frequency, again following Dees et al. (2007). The stock market value and gross capital formation were deflated by the price index, CPI_{it}. Data is from FRED, OECD, and World Bank and cover the period between 1990M1 and 2018M12. Bilateral trade data is from Mohaddes and Raissi (2020). In the case of the World Bank data (investment and CO2 emissions), we implemented the Denton procedure to change the frequency from annual to monthly. Table 1 summarizes our key variables and their sources.

Table 1: Main variables

Variable	Definition	Source
S	short-term interest rate	OECD Main Economic Indicators
L	long-term interest rate	OECD Main Economic Indicators
Q	share price index (2015 = 100)	OECD Economic Outlook
GCF	Gross capital formation (constant 2015 US$)	World Bank national accounts data
CPI	consumer price index (2015 = 100)	OECD Main Economic Indicators
CO2	CO2 emissions (kt)	Climate Watch.2020/World Resources Institute/World Bank

Our sample comprises 19 countries, including advanced and emerging economies. This distinguishes our paper from the literature: we consider the international economy explicitly instead of treating countries as closed economies, which is the usual practice in time-series studies (Chishti et al., 2021). We construct Eurozone variables as a weighted average of 8 countries (Austria, Belgium, Finland, France, Germany, Italy, Netherlands, and Spain), with weights given by GDP (PPP). This is standard in GVAR works (Pesaran et al., 2004; Dees et al., 2007). Therefore, we have 12 regions in the model: the regions of interest – U.S., U.K., Japan (JPN) and the Eurozone (EURO) –, and 8 other countries that we use to characterize the international economy: Brazil (BRA), Canada (CAN), Korea (KOR), Norway (NOR), South Africa (SOU), Sweden (SWE), Switzerland (SWI) and Turkey (TUR).

Following the description of the GVAR, we create two new vectors. The first is a vector that includes of regions i's domestic and foreign variables: $z_{it} = (x_{it}, x_{it}^*)'$. The second is a global vector, which incorporates domestic variables for all economies: $x_t = (x_{0t}', x_{1t}', x_{2t}', x_{3t}', \dots, x_{Nt}')'$. In this last vector, each term denotes the domestic variables of a specific region. For instance, for region zero, we have: $x_{0t} = (s_{0t}, l_{0t}, q_{0t}, gcf_{0t}, \pi_{0t}, co2_{0t})'$. From these vectors, we write the identity: $z_{it} = W_i x_t$, where W_i is the "link" matrix, whose first rows retrieve x_{it} from x_t, and the last rows compute the trade-weighted average as in (19). Substituting this identity in equation (18) and stacking all the equations:

$$G x_t = a_0 + a_1 t + H x_{t-1} + \varepsilon_t \qquad (22)$$

where: $a_0 = \begin{pmatrix} a_{00} \\ a_{10} \\ a_{20} \\ \ldots \\ a_{N0} \end{pmatrix}, a_1 = \begin{pmatrix} a_{01} \\ a_{11} \\ a_{21} \\ \ldots \\ a_{N1} \end{pmatrix}, \varepsilon_t = \begin{pmatrix} \varepsilon_{0t} \\ \varepsilon_{1t} \\ \varepsilon_{2t} \\ \ldots \\ \varepsilon_{Nt} \end{pmatrix}, G = \begin{pmatrix} A_0 W_0 \\ A_1 W_1 \\ A_2 W_2 \\ \ldots \\ A_N W_N \end{pmatrix},$

$H = \begin{pmatrix} B_0 W_0 \\ B_1 W_1 \\ B_2 W_2 \\ \ldots \\ B_N W_N \end{pmatrix}, A_i = [I_{k_i}, -\Lambda_{i0}]$ and $B_i = [\Phi_i, \Lambda_{i1}]$.

In general, matrix G is nonsingular. Hence we can use its inverse to generate the GVAR:

$$x_t = G^{-1}a_0 + G^{-1}a_1 t + G^{-1}Hx_{t-1} + G^{-1}\varepsilon_t \qquad (23)$$

When working with times series, stationarity tests can indicate the existence of unit roots. In these situations, the GVAR is used in the error correction form, with the model written in first differences (Pesaran et al., 2004):

$$\Delta x_{it} = a_{i0} + a_{i1}t + \Pi_i v_{i,t-1} + \Lambda_{i0}\Delta x_{it}^* + \psi_{i0}\Delta d_t + \varepsilon_{it}, \qquad (24)$$

where $\Pi_i = (A_i - B_i, -\psi_{i0} - \psi_{i1})$ and $v_{it-1} = \begin{pmatrix} z_{i,t-1} \\ d_{t-1} \end{pmatrix}$.

In equation (24), the vector d_t represents global variables, which do not depend exclusively on a specific region. Examples are World GDP and commodity prices. The error correction form allows us to analyze long-term relations between variables. This is particularly advantageous here since we are interested in capturing the effects of monetary policy on CO2 emissions in the short- and the long-run.

3.1 Unit root and cointegration tests

Before turning to our main empirical results, we present unit root and cointegration tests, which allow us to verify whether we can use the GVAR in the error correction form.

Tables 2 and 3 examine the stationarity of domestic and external variables for each region. Following Dees et al. (2007), we use the Weighted Symmetric (WS) unit root test. According to these authors, WS performs better than the ADF test. Although we report only the estimates of the WS test, ADF test results confirmed the main conclusions from Tables 2 and 3. A variable has a unit root if its test statistic is lower than the critical value (C.V.). Values highlighted in bold indicate the presence of a unit root.

Table 2: WS unit root test statistics for domestic variables

Domestic variables	C.V.	Regions											
		BRA	CAN	EURO	JPN	KOR	NOR	SOU	SWE	SWI	TUR	UK	US
q	-2,55	**-0,02**	**-1,25**	**-1,82**	**-1,72**	**-2,40**	**-0,60**	**-1,14**	**-1,00**	**-0,52**	-3,20	**-1,81**	**-0,59**
Δq	-2,55	-11,05	-8,91	-11,20	-7,53	-11,65	-8,94	-9,28	-10,75	-11,64	-12,79	-10,05	-12,39
co2	-2,55			**-0,82**	**-2,25**							**1,14**	**-1,57**
Δco2	-2,55			-6,25	-5,53							-9,85	-5,20
s	-2,55		**0,08**	**-0,31**	**-2,48**		**-1,13**	**-1,05**	**-0,15**	**0,75**		**0,02**	**-0,89**
Δs	-2,55		-9,52	-6,41	-4,92		-8,38	-9,03	-12,22	-8,67		-6,09	-9,87
π	-2,55	**2,54**	4,41	3,37	**2,03**	4,13	3,52	**2,03**	3,05	**2,48**	**0,99**	**2,12**	3,49
$\Delta\pi$	-2,55	**-0,57**	-12,90	-6,33	-6,73	-6,68	-10,13	-5,56	-4,65	-4,44	**-2,46**	-3,13	-11,88
l	-2,55		**0,06**	**-0,16**	**1,04**		**-0,28**	**-1,47**	**0,10**	**-0,13**		**0,51**	**-0,93**
Δl	-2,55		-9,52	-7,74	-11,55		-8,31	-11,86	-7,93	-8,27		-12,62	-9,21
gcf	-2,55		**0,07**	**0,26**	**-2,00**	**1,09**	**-0,36**	**-0,23**	**-0,57**	**0,12**	**0,27**	**0,21**	**0,52**
Δgcf	-2,55		-8,02	-5,24	-3,97	-6,41	-3,63	-5,64	-5,43	-5,43	-8,59	-7,15	-4,06

Notes: C.V. stands for the critical value. In blank cells, the test could not be implemented because of missing values. Values highlighted in bold denote the presence of a unit root.

Table 3: WS unit root test statistics for foreign variables

Foreign variables	C.V.	Regions											
		BRA	CAN	EURO	JPN	KOR	NOR	SOU	SWE	SWI	TUR	UK	US
q*	-2,55	**-1,53**	**-0,80**	**-0,95**	**-1,05**	**-1,53**	**-1,55**	**-1,57**	**-1,46**	**-1,63**	**-1,55**	**-1,44**	**-1,49**
Δq*	-2,55	-11,69	-12,23	-11,85	-12,08	-11,41	-11,40	-11,37	-11,15	-11,40	-11,43	-11,18	-11,02
co2*	-2,55	**-0,99**	**-1,47**	**-0,38**	**-1,15**	**-1,32**	**-0,06**	**-0,68**	**-0,47**	**-0,42**	**-0,47**	**-0,91**	**-0,67**
Δco2*	-2,55	-5,72	-5,26	-5,79	-5,55	-5,25	-8,17	-5,99	-6,50	-6,53	-6,49	-6,11	-5,74
s*	-2,55	**0,12**	**-0,64**	**0,02**	**-0,09**	**-0,01**	**0,00**	**-0,04**	**-0,27**	**-0,04**	**-0,06**	**-0,18**	**0,13**
Δs*	-2,55	-7,46	-9,84	-7,09	-9,43	-7,65	-7,09	-6,96	-6,37	-6,86	-6,68	-6,72	-7,89
π*	-2,55	3,74	3,89	**2,02**	**2,08**	**2,20**	**2,03**	**2,06**	2,98	**1,94**	**2,07**	**1,91**	**2,46**
Δπ*	-2,55	-5,75	-6,03	**-0,85**	**-1,86**	**-1,27**	**-1,93**	**-1,06**	-3,73	-2,98	**-2,37**	-3,18	**-0,61**
l*	-2,55	**-0,29**	**-0,73**	**-0,15**	**-0,47**	**0,04**	**-0,09**	**-0,12**	**-0,15**	**-0,16**	**-0,17**	**-0,24**	**-0,01**
Δl*	-2,55	-8,38	-9,05	-8,12	-8,65	-8,57	-7,66	-8,01	-7,76	-7,93	-7,85	-7,98	-8,21
gcf*	-2,55	**0,75**	**0,58**	**0,64**	**0,90**	**0,31**	**0,62**	**0,57**	**0,39**	**0,59**	**0,59**	**0,55**	**0,64**
Δgcf*	-2,55	-4,97	-4,14	-6,43	-5,01	-4,64	-6,02	-5,64	-4,90	-5,77	-5,62	-5,53	-6,84

Notes: C.V. stands for the critical value. Values highlighted in bold denote the presence of a unit root.

Unit-root tests indicate that most variables are nonstationary in levels, but stationary when we take first differences. Hence, we can apply cointegration tests to verify if there are long-term relationships between them.

Table 4 displays the results for the maximum eigenvalue test. The null hypothesis is that there are at most r cointegrating relations. We start with $r = 0$ and increase r until we obtain a rejection of the null hypothesis, which occurs when the test statistic is smaller than the critical value (highlighted in bold).

Critical values vary according to the number of foreign variables. As the U.S. has a different number of foreign variables than the rest of the sample, we separated this country to present its specific critical value. Except for Brazil, the tests indicate the existence of cointegrating relations in all regions. Thus, we can use the GVAR in the error correction form. More importantly, the model can provide information about long-term relationships, which is one of our objectives in this article.

Table 4: Maximum Eigenvalue test statistics

Ho	H1	Regions											C.V.
		BRA	CAN	EURO	JPN	KOR	NOR	SOU	SWE	SWI	TUR	UK	
r = 0	r = 1	**37,89**	73,62	230,01	101,74	154,57	74,12	105,12	195,30	173,46	137,73	128,49	51,06
r ≤ 1	r = 2	20,17	**39,86**	104,88	96,19	65,84	51,04	66,56	72,16	88,31	83,93	90,61	44,84
r ≤ 2	r = 3		25,60	78,00	59,44	**10,59**	**24,48**	**22,57**	**23,89**	**34,05**	**23,87**	41,37	38,55
r ≤ 3	r = 4		13,06	**29,60**	42,85		22,36	20,66	19,00	24,29		37,46	32,15
r ≤ 4	r = 5		8,38	23,02	**21,03**		11,92	12,23	15,60	7,59		27,28	25,50
r ≤ 5	r = 6			8,12	7,03							**10,59**	18,26

Ho	H1	US	C.V.
r = 0	r = 1	147,04	47,79
r ≤ 1	r = 2	126,13	41,62
r ≤ 2	r = 3	53,39	35,38
r ≤ 3	r = 4	31,91	29,04
r ≤ 4	r = 5	11,47	22,50
r ≤ 5	r = 6	**5,03**	15,46

Note: C.V. stands for critical value at 5% significance. BRA, KOR, and TUR have values only for the first rows because of the small number of observations for domestic variables. The null hypothesis is that there are at most *r* cointegrating relations. We start with *r* = 0 and increase *r* until we obtain the first rejection of the null hypothesis (highlighted in bold above), which occurs if the test statistic is smaller than the corresponding critical value.

The next step is to define the VARX(p,q) order for each region and the number of cointegrating relations, where p is the number of lags included for domestic variables and q is the number of lags for foreign variables. Table 5 shows these setups. Following the Akaike criterion, for all regions we use two lags for the domestic variables, and one or two lags for the foreign variables. We limit the number of cointegrating relations because of stability concerns. Smith and Galesi (2014) argue that, in general, a high number of relations generates unstable models. The recommendation, under these circumstances, is to reduce them until the model produces stable responses. We followed this procedure here.

Table 5: VARX order and number of cointegrating relations

Regions	VARX order		Cointegrating relations
	p	*q*	
BRA	2	1	1
CAN	2	2	1
EURO	2	1	2
JPN	2	2	2
KOR	2	2	1
NOR	2	1	1
SOU	2	2	1
SWE	2	2	1
SWI	2	2	1
TUR	2	2	1
UK	2	2	2
US	2	1	1

4. Results

This section presents results from our estimations. We first discuss our main empirical exercises regarding the effect of monetary policy on CO2 emissions. Our analysis is based on Generalized Impulse Response Function (GIRFs) obtained from simulating the impact of a monetary shock. We then present results for the long-run relationship between these variables obtained through cointegration. Finally, we discuss the international economy's role in explaining CO2 emissions, based on outcomes from the Generalized Forecast Error Variance Decomposition (GFEVD).

4.1 Monetary shocks and CO2 emissions

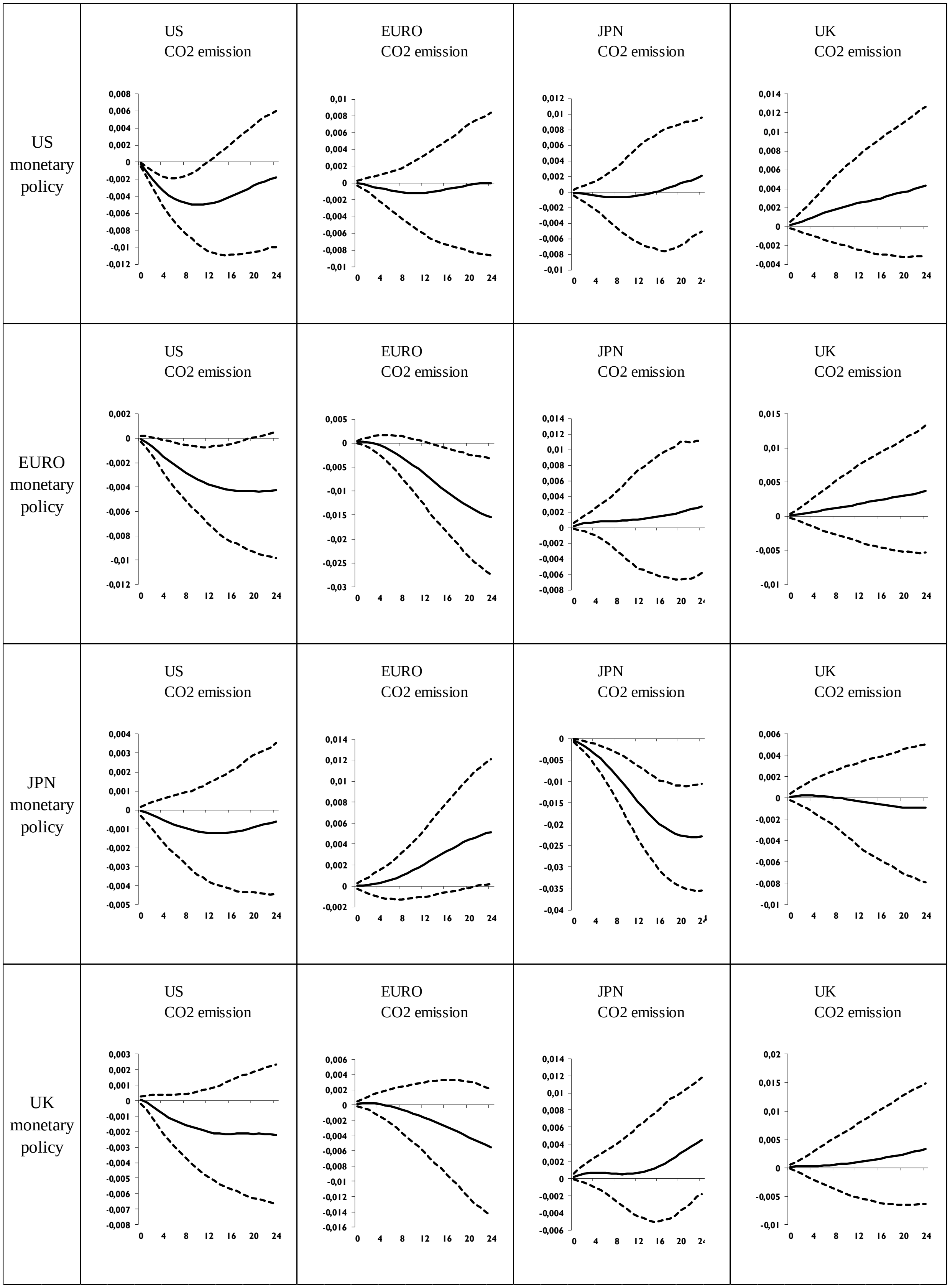
In this subsection, we analyze monetary shocks in the four regions of interest: the U.S., Japan, the Eurozone, and the U.K. Our main goal is to verify the effect of these shocks on CO2 emissions. Figure 1 presents GIRFs depicting the reaction of CO2 to a shock of one standard deviation in the short-term interest rate of each of the four regions. We use 90%

confidence intervals calculated using bootstrap (dashed lines). Values in the vertical axis are percentages.

We are interested in the effect not only in the region that suffers the shock, but also on how it spreads to other economies. In this sense, Figure 1 should be read as a matrix, with plots in the diagonal representing the effect of a shock in region *i* on its own emissions, and off-diagonal plots representing cross-region effects. For instance, the plot in row 2, column 1 shows the response of U.S. emissions to a monetary contraction in the Eurozone. We focus on 24-month windows after each shock.

Our results indicate that a monetary contraction is indeed associated with a reduction in domestic CO2 emissions. In all diagonal plots, emissions follow a decreasing path in the aftermath of a monetary shock. The effect is significant for the first 12 months in the U.S., whereas Japan and the Eurozone display effects that are larger in magnitude and significant for almost the whole period. The exception is the U.K., whose GIRF is insignificant in all 24 months. On the other hand, we find little evidence of cross-region effects of monetary policy on emissions since off-diagonal GIRFs are mostly indistinguishable from zero at conventional levels.

Figure 1: Response of CO2 emissions to contractionary monetary shocks

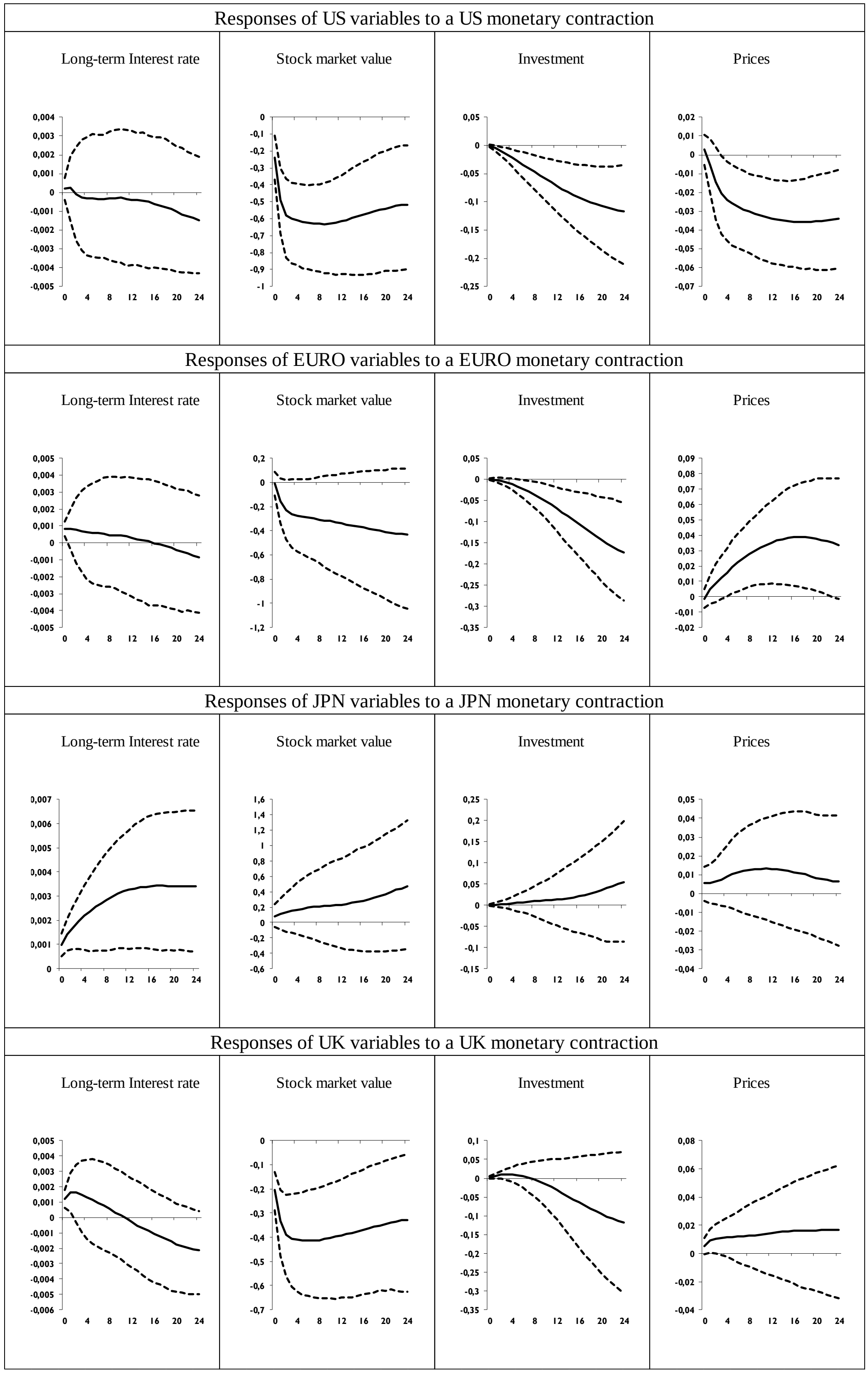


To complement our analysis, Figure 2 shows GIRFs for other variables included in the GVAR. Here we focus on domestic responses to a monetary contraction. For the U.S., we see a drop in the stock market value, the price level and investment, but the effect on the long-term interest rate is insignificant. Interestingly, we find no evidence of a price puzzle in U.S. data.

In the Eurozone, investment also falls in response to a monetary contraction, while the effects on stock markets and the long-run interest rate are mostly insignificant. We detect a price puzzle here, but this response is transitory and eventually becomes insignificant. In Japan, the long-term interest rate rises, but the effects on the stock market, investment, and the price level are insignificant.

The U.K. is the only region with significant responses of both financial variables - at least in some periods. The effect on the long-term interest rate is significant only in the first two months. Similarly to the U.S., we detect a negative stock market reaction. Nonetheless, the response of investment is not statistically significant.

Figure 2: Responses of domestic variables to a domestic monetary contraction



4.2 Long-run effects

Cointegration analysis allows us to investigate the long-run relationship between monetary policy and emissions. As we checked in subsection 5.1, most variables have a unit root. GVAR deals with nonstationarity by taking the first differences of series. When we apply this procedure, we can use the model in the error correction form and analyze long-term relations.

Table 6 provides the coefficients of the cointegrating relation between CO2 emissions and two critical variables: the short-term interest rate and investment. The first represents monetary policy, and the second is a possible channel between economic activity and CO2. In the cointegrating equation, we normalize the value of the coefficient of emissions to 1. In the table, an asterisk indicates statistical significance at 5%.

Table 6: Cointegration coefficients of CO2 emissions (normalized)

Regions	Short-term interest rate	Investment
US	-4.10*	0.03*
JPN	-116.01*	0.11*
EURO	3.79*	0.16*
UK	-9.18*	0.39*

Note: * denotes statistical significance at 5%.

In all regions, the coefficients are statistically significant at 5%, with the expected signs except for the short-term interest rate in the Eurozone, which has a positive sign. For the U.S., Japan and U.K., the cointegrating relations indicate that a contractionary monetary policy is related to decreasing levels of CO2 emissions in the long run. Furthermore, the second column of Table 6 confirms the results from the GIRFs: investment and CO2 emissions tend to comove in all regions.

4.3 Variance decompositions

Our empirical results suggest that the effect of monetary policy on pollution is basically domestic: a monetary contraction in a region reduces its own emissions, but this does not seem to spread out to other economies. However, this does not imply that the international economy is irrelevant to determining one region's emissions level. We can see that in our last econometric exercise, which explores one of the main advantages of the GVAR methodology.

The Generalized forecast error variance decomposition (GFEVD) allows us to verify the influence of domestic and external factors in explaining the fluctuations of a specific variable. Here we focus on how these factors drive the changes in CO_2 emissions. In short, we promote shocks to a country's CO_2 and evaluate the direct effect on emissions, as well as feedbacks through other variables, including those of other regions.

Table 7 shows the results of this analysis. For each region, we decompose changes in CO_2 emissions into domestic factors and external factors, i.e., that originate from the other three regions. We normalized values so that they add up to 100% across each row.

Table 7: GFEVD of CO_2 emissions

US										
	Domestic factors						External			
	q	*co2*	*s*	*π*	*l*	*gcf*	US	EURO	UK	JPN
1	0,25	54,91	1,97	0,04	0,37	21,88		5,36	7,11	8,11
4	0,07	53,51	3,53	0,03	0,93	21,03		5,96	7,08	7,87
12	1,12	47,20	2,88	1,93	4,31	19,39		8,17	7,47	7,52
24	1,94	32,17	1,29	9,59	9,27	17,69		12,57	9,00	6,47

EURO										
	Domestic factors						External			
	q	*co2*	*s*	*π*	*l*	*gcf*	US	EURO	UK	JPN
1	0,31	40,22	0,12	0,83	0,01	18,72	9,33		20,99	9,47
4	0,09	39,90	0,03	1,74	0,03	18,06	10,09		20,30	9,76
12	0,29	37,66	0,93	4,44	0,74	16,36	10,75		18,44	10,40
24	1,70	31,05	4,37	9,57	2,90	14,14	10,73		15,31	10,23

UK										
	Domestic factors						External			
	q	*co2*	*s*	*π*	*l*	*gcf*	US	EURO	UK	JPN
1	0,65	40,02	0,04	1,35	0,18	15,73	15,01	18,23		8,79
4	1,13	39,84	0,02	1,97	0,56	15,82	14,36	17,79		8,51
12	1,40	40,49	0,02	2,43	0,84	15,84	13,61	16,97		8,41
24	1,28	41,41	0,08	2,63	0,59	15,96	13,22	16,14		8,69

JPN										
	Domestic factors						External			
	q	*co2*	*s*	*π*	*l*	*gcf*	US	EURO	UK	JPN
1	0,03	59,42	1,02	1,32	1,50	27,17	4,34	2,89	2,31	
4	0,18	56,85	2,20	3,43	2,03	26,05	4,20	2,73	2,34	
12	0,86	44,23	10,39	11,82	2,57	19,03	5,07	3,61	2,40	
24	0,80	21,69	29,19	14,88	6,15	8,49	8,26	8,56	1,98	

Table 7 shows that domestic factors are dominant in explaining CO_2 fluctuations in all four regions, with the movements in this variable coming mostly from shocks to itself, followed by repercussions through investment. Nonetheless, external factors are also relevant. After 24 months, the feedbacks through the international economy account for 28% of CO_2 emissions in the U.S., 36% in the Eurozone, 38% in the U.K., and 19% in

Japan. Hence, GVAR estimations show the importance of considering the dynamics of trade partners to understand domestic CO_2 emissions.

5. Conclusion

Can monetary policy affect the environment? Our paper suggests that it can. We first propose a simple extension of the AS/AD model to illustrate the relationship between monetary policy and CO_2 emissions. We then go to the data. Specifically, we use the GVAR methodology, which explicitly connects regions, in our case through international trade. Thus, we characterize the international economy, instead of treating each region as separate from the rest of the world. This is important in our context, given the widespread notion that emissions are associated with negative cross-border externalities.

We focus on CO_2 emissions in four key regions – U.S., U.K., Japan and the Eurozone – and use data from 8 other countries to build the international economy. Estimated GIRFs imply that a contractionary monetary shock drives down emissions over time in all regions except the U.K. Moreover, cointegration analysis indicates that this relationship holds in long run for the U.S., U.K. and Japan.

Although we find no evidence of cross-region effects of monetary shocks, variance decompositions show that the international economy is quantitatively relevant to understand movements in CO_2 emissions of each region. This result suggests efforts to reduce emissions can benefit from internationally coordinated policies. We, however, leave this issue for future research.

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