Can the Federal Reserve Save the Environment? *

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Abstract

This paper studies the effect of monetary policy on environmental quality via the channel of global value chains (GVCs). From a proxy-VAR analysis with U.S. monetary policy surprise as an external instrument, we show that a contractionary monetary policy which escalates domestic credit costs and induces stronger local currency has a causal effect of reducing emissions but raising emission intensities due to firms' discouraged participation to the GVCs. This result indicates that monetary policies can be one of the policy instruments addressing environmental issues.

JEL codes: E52, F18, F41, Q53
Keywords: Emission; Emission Intensity; Global Value Chain; Monetary Policy; Domestic Credit Cost; Real Effective Exchange Rate

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1 Introduction

According to environmental, trade and macroeconomic data, industrial sectors of the United States (U.S.) have become cleaner during the past few decades. This has occurred alongside the expansion of international trade via the global value chains (GVCs) and the overall currency depreciation.[1] This paper aims to discover the causal linkage between the variation of dollar-value and environmental quality particularly through the channel of intermediate input trade.

U.S. monetary policy is one of the key factors determining domestic credit costs and foreign exchange rates (Bruno et al., 2018). When the Federal Reserve tightens its monetary policy, U.S. nominal interest rates rise which, in turn, induces greater credit costs for enterprises and encourages carry traders to purchase U.S. bonds.[2] The increase in demand for U.S. bonds causes an appreciation of dollars in the short run and the international trade activities of the U.S. firms in the GVCs are affected accordingly. An increase in domestic credit costs discourages firms' production activity and their participation in the globally fragmented manufacturing processes. Furthermore, an appreciation of dollars in the foreign exchange markets results in a loss in price competitiveness when the U.S. exports goods since the foreign prices of U.S. commodities become relatively more costly compared to foreign substitutes. Considering this mechanism of the economy, we build a partial equilibrium model followed by a proxy-vector autoregression (VAR) method to study the effect of U.S. monetary policy on the domestic environmental quality through the lens of GVC activities of the U.S.

The key finding of this paper is that a contractionary monetary policy has a short-run effect of reducing domestic emissions of carbon dioxide (CO_2, Mmt) while escalating emission intensities (i.e., CO_2 per billion dollars). As illustrated earlier, this is due to discouraged international trade of intermediate inputs via GVCs which, in turn, negatively affects the economy in generating value-added. We specifically show that the indirect domestic and foreign value-added contents in gross exports shrink—which are respectively associated with the forward and backward linkages of the U.S. in the GVCs—as a consequence of a monetary policy inducing an appreciation of dollars. Domestic industrial production activities dwindle and total generation of pollutants diminishes

[1] See Levinson (2009), Cherniwchan (2017), Shapiro and Walker (2018), Bruno et al. (2018), and Wei and Xie (2020). More empirical details are provided in Section 2.

[2] See Anzuini et al. (2012) for details.

accordingly. Emission intensity rises, in contrast, since discouraged GVC activities entail a significant loss in production efficiency which the U.S. could have otherwise captured from efficiently established global manufacturing systems.

One of the policy implications of the findings is that a contractionary monetary policy can be an effective tool in lowering total emissions. However, the improved air quality is achieved at the expense of economic slowdowns. Since it is, in general, necessary to fulfill both economic stability and sustainable environment, we mainly focus on the measure of emission intensity. The findings we suggest in this paper indicate that a contractionary monetary policy—which raises domestic credit costs and thus discourages firms to participate in the GVCs—can be detrimental in lowering emission intensities. This implies that implementing an expansionary monetary policy could be effective in generating less amount of pollutants per unit of value-added. This paper is insightful because it shows the positive externality of an expansionary monetary policy on the domestic environmental quality. To this end, the role of monetary policy as an indirect but powerful instrument of improving environmental quality can potentially be apparent especially when the government's environmental policies are ineffective in the phase of significant economic downturns like 1997 Asian financial crisis, 2008-2009 global financial crisis or even 2020 COVID-19 pandemic crisis.

To demonstrate the efficacy of the mechanism we propose, we first build a partial equilibrium model which assumes that the representative multinational enterprise (MNE) decides the extent of offshoring tasks abroad in response to higher domestic credit costs which may arise from a contractionary monetary policy. The offshoring behavior of a MNE represents the degree of GVC participation of a country which affects both the generation of value-added and emissions via intermediate input trade. We show that greater credit costs lead to lower emissions but higher emission intensities due to discouraged offshoring activities of the MNE which, in turn, induces a significant reduction in value-added.

Second, we apply a proxy-VAR method using U.S. monetary policy surprises as an external instrument to demonstrate the causal effect of a contractionary monetary policy on domestic environmental quality of the U.S.[3]. To better account for changes in the value of U.S. dollar in response

[3] By capturing exogenous variation in the shock of interest, an instrument can help estimate dynamic causal effects of macroeconomic shocks. For details, see Stock and Watson (2018)

to a monetary shock, we use monthly data on real effective exchange rates (REER) which is a trade weighted measure of the relative value of a local currency compared to the basket of currencies of trade partners. We additionally consider several other important factors such as imports, exports, industrial production, CO_2 emissions, and emission intensity of the U.S. from August 2001 to August 2017. To determine forward and backward linkages of the U.S. in GVC activities, we also collect monthly indirect domestic value added in gross export (IDC) and foreign value-added content in gross export (FVA) from January 2002 to December 2011.[4]

We define a monetary policy surprise by the changes in the Fed Funds futures rate 10 minutes before and 20 minutes after the Federal Open Market Committee (FOMC) announcement. Within this 30-minute window, the monetary policy surprise measures the unanticipated component of the Fed's decision on the Fed Funds rate target. We employ a monetary policy surprise as an external instrument for REER because it is closely related with the movement of REER and we believe that it affects the generation of emissions only through the variations in REER which affects production and trade activities. By identifying the impulse responses of the emissions to a monetary policy shock, we demonstrate the impact of credit costs on the environmental accounts of the U.S.

The finding of this paper introduces a novel insight to the trade-environment literature which has focused on multiple channels through which the environmental quality is affected in a highly globalizing world. From a wide academic endeavor, it has been well-known that free international trade is one of the contributors keeping the environment "greener" via firm-sorting,[5] intensified innovation and/or encouraged abatement investments arising from foreign competitions.[6] As production fragmentation has become an important feature of international trade for the past few decades, intermediate input trade (i.e., outsourcing production) through the global value chains (GVCs) has also been spotlighted as an additional determinant of domestic environmental quality.[7] This paper is in line with this recent trend of literature in the sense that we consider the en-

[4]Since the data on monthly-level indirect domestic value-added contents and foreign value-added contents in the U.S. gross export do not exist, we had to impose an assumption that the annual forward and backward participation rates of the U.S. are consistent across months within a year. We multiply the participation rates to the monthly gross export data to derive proxy measures of monthly IDC and FVA.

[5]Thanks to the availability of micro-data, changes in industry composition caused by trade liberalization have been nailed down to firm, plant and even task-level compositional changes. See Cherniwchan et al. (2016) for detail.

[6]Composition and technique effects caused by trade liberalization are well documented in Antweiler et al. (2001); Grether et al. (2009); Levinson (2009); Forslid et al. (2011); Martin (2011); Baldwin and Ravetti (2014); Kreickemeier and Richter (2014); Cui et al. (2015); Holladay (2016); Barrows et al. (2016), Cherniwchan (2017); Forslid et al. (2018) and many others.

[7]See, for example, Dean and Lovely (2010); Dietzenbacher et al. (2012); Meng et al. (2015) Li and Zhou (2017); Cole

vironmental consequences of forward and backward linkages of the U.S. in the GVCs. We move one step further by studying the dynamics of GVC activities of the U.S. in response to exchange rates and domestic credit costs influenced by the U.S. monetary policy and its impact on the environmental quality which have yet been studied.

This paper is also aligned to the past studies which investigate the cross-border spillover of U.S. monetary policy on exchange rate.[8] It has been well known that a contractionary U.S. monetary policy is associated with persistent appreciation in the U.S. real exchange rates (Eichenbaum and Evans, 1995).[9] Thus, the exchange rate pass-through from monetary policies plays a crucial role in determining international trade activities since the prices of import and export goods alter by the changes in the value of local currency.[10] For example, Wei and Xie (2020) show that policymakers have to consider the dependence of their economies on GVCs when they design a monetary policy. Also, Bruno et al. (2018) find that a weaker local currency against the dollar is associated with tighter credit conditions and discourages global value chain activity. We study environmental externality arising from monetary policy particularly through the changes in exchange rates and international trade activities via input-output linkages which has not been analyzed in the past studies. We aim to fill this gap in the literature.

The rest of the paper is organized as follows. Section 2 introduces stylized facts which portray potential linkages between exchange rates, domestic credit costs, international trade via global value chains and the environmental quality. Section 3 provides one of the theoretical mechanisms we propose to explain the phenomena described in Section 2. Sections 4 and 5 respectively illustrate the empirical identification strategy, and the causal effect of monetary policy on the domestic environmental quality. Section 6 discusses the policy implications of the findings of this paper and Section 7 concludes.

et al. (2017) and Liu et al. (2018)

[8]See, for example, Rey (2016); Georgiadis (2016); Forbes et al. (2018) and Iacoviello and Navarro (2019).

[9]According to exchange rate overshooting models, an appreciation—associated with a contractionary monetary policy—would be followed by a depreciation in currency value. For details, see Dornbusch (1976) and Bjørnland (2009).

[10]See, for example, Baldwin and Krugman (1989); Bacchetta and Van Wincoop (2000); Héricourt and Poncet (2015); Chen and Juvenal (2016); Asteriou et al. (2016) and Bussière et al. (2020).

2 Motivating Facts

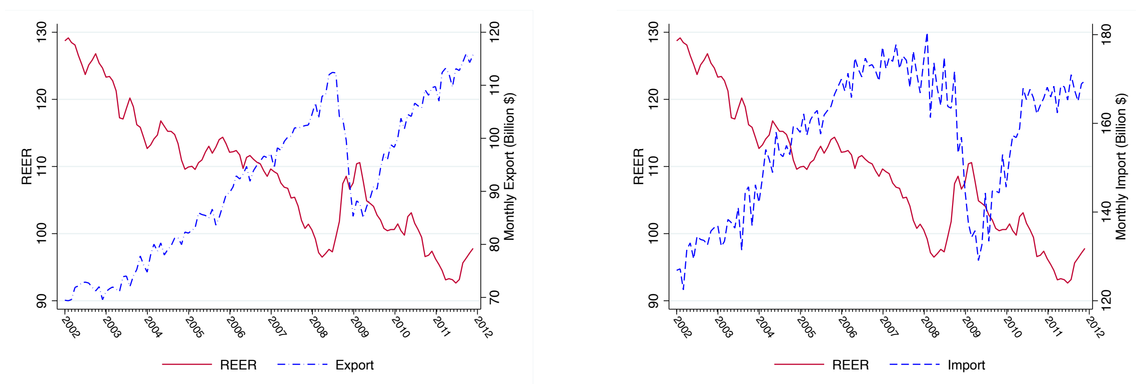
In this section, we introduce empirical evidence revealing the correlation between environmental, macroeconomic and supply chain measures.

First, we focus on the historical international trade activities of the U.S. via (monthly) gross exports and imports together with the trend of exchange rates since the relative value of the U.S. dollar compared to foreign currencies directly impact the extent of international trade.

Figure 1 portrays that both exporting and importing activities of the U.S. have dramatically increased despite a down-turn during the 2008-2009 global financial crisis. From the real effective exchange rates (REER)—which its escalation reflects the appreciation of U.S. dollar compared to the basket of trade partners' currencies—we can also observe that the relative value of the U.S. dollar has been depreciated over time and it shows the opposite pattern to those of gross exports and imports.

Figure 1: REER and International Trade Activity of the U.S.

(a) REER and Gross Export (b) REER and Gross Import



Notes: These figures describe correlations between real effective exchange rates, gross (monthly) exports and imports. *Source:* Bureau of Economic Analysis.

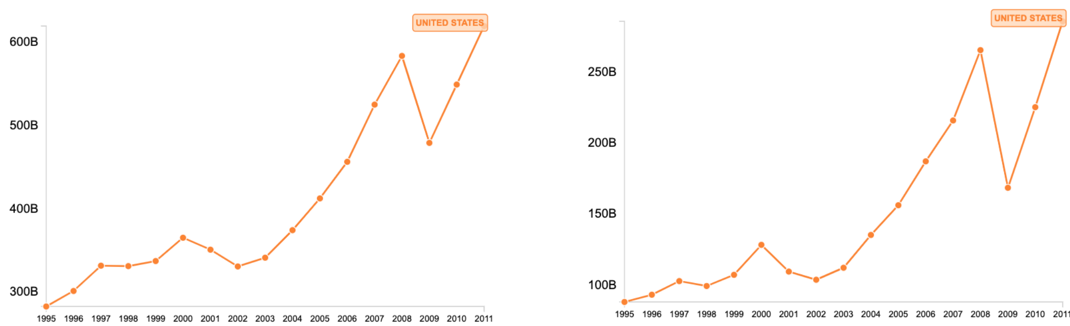
The negative correlation of gross export and REER can be understood based on international trade theory that the depreciation of U.S. dollar induces foreign price of U.S. commodities less costly compared to competing foreign goods which, in turn, augments the volume of gross exports. Interestingly, however, it is less intuitive to understand the negative relationship between REER and gross imports because the depreciation of the U.S dollar causes foreign goods to be more costly to import. We view this seemingly ironic phenomenon as a suggestive evidence that exporting and importing activities are closely connected in the modern economy in which a variety of goods are produced through multi-stage intermediate input trades occurring in the globally fragmented manufacturing processes. In other words, importing activities can be encouraged despite the depreciation of local currencies if exports embed a large share of foreign value-added.

Second, to demonstrate the validity of our view, we explore the trend of indirect domestic (IDC) and foreign value-added (FVA) contents in gross exports. IDC reflects the value-added from domestically produced intermediate inputs incorporated in gross exports. FVA indicates the value-added of foreign intermediate inputs embedded in U.S. exports. Thus, IDC and FVA represent the extent to which the U.S. is involved in the global value chain and specifically these measures are associated with the forward and backward linkages of the U.S.

Figure 2: Trends in Forward and Backward GVC Participation

(a) Indirect Domestic Content in Gross Export

(b) Foreign value-added in Gross Export



Notes: These figures portray the extent of GVC participation of the U.S. in terms of indirect domestic (IDC) and foreign value-added (FVA) content in gross (annual) exports from 1995 to 2011. IDC and FVA respectively illustrate the forward and backward GVC linkages of the U.S in the value chain. The unit of the measure is current U.S. billion dollars. *Source:* The World Bank, TCdata360 (OECD-TiVA).

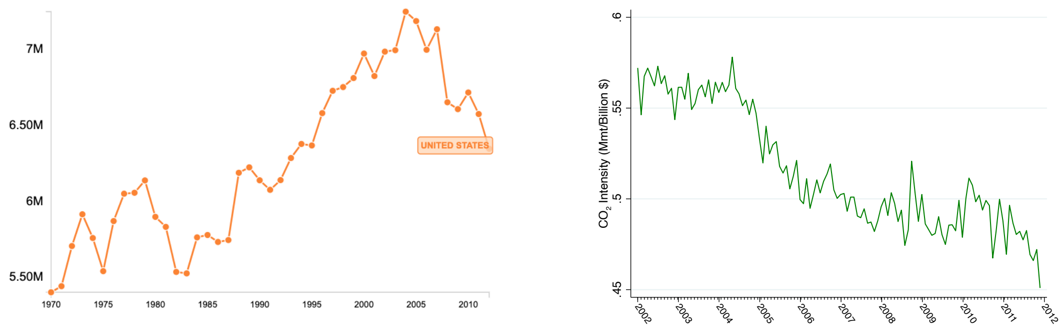
Figure 2 describes that both forward and backward participation of the U.S. to the value chain have, on average, increased and the patterns of the two depict a close similarity. This implies that exporting and importing activities of intermediates are positively linked especially in the context of global value chains.

Lastly, we focus on the time variation of total greenhouse gas (GHG) emissions and intensity of carbon dioxide (CO_2)—which takes approximately 80% of the total GHG—of the U.S. Total emission of GHG is measured by kiloton in CO_2 equivalent, and emission intensity is defined as the amount of CO_2 in million metric ton per billion U.S. dollars.[11]

[11]We obtain monthly CO_2 emissions from broadly defined industrial sectors in the U.S. from the EIA. We focus on

Figure 3: Trends in Environmental Accounts

(a) Total Greenhouse Gas Emissions (b) Emission Intensity (CO_2)



Notes: Figures show the historical trend of total greenhouse gas emissions and emission intensity of carbon dioxide respectively from 1970-2012 and 2002-2011. The unit of the first panel is kt of CO_2 equivalent, and that of the second panel is Mmt of CO_2 per billion dollars (constant, 2010 \$, seasonality adjusted). *Source:* The World Bank, TCdata360 (OECD-TiVA), Global Economic Monitor (World Bank) and Energy Information Administration (EIA).

Figure 3 depicts two contrasting patterns in total emission and emission intensity. We can observe that the volume of air pollutants has overall increased for the past few decades similar to the expansion of international trade and the participation of the U.S. in the global value chains as illustrated in figures 1 and 2. Interestingly, however, the U.S. has become increasingly "cleaner" per billion dollars despite the encouraged production activities associated with international trade. The goal of this paper is to investigate one of the mechanisms behind this phenomenon. We ultimately aim to reveal the link between domestic credit costs which can be represented by the changes in REER and emission intensity in CO_2 particularly through the channel of GVCs.[12]

In the next section, we introduce a conceptual framework providing an intuition regarding a potential mechanism behind the stylized facts illustrated thus far.

3 Conceptual Framework

We borrow insights from Bruno et al. (2018) which demonstrate that stronger dollar and tighter domestic credit conditions for working capital are positively associated, and these two factors dampen international trade activities in the GVCs. To show the causal effect of monetary policy on the environmental accounts, we first theoretically focus on how domestic air quality varies by

industrial carbon emissions due to its close relationship with the production fragmentation processes.

[12]We focus on carbon dioxide since (a) it takes a major portion of greenhouse gasses, and (b) due to data availability.

domestic credit condition, and then empirically study how the environmental quality alters by the variation of (real effective) exchange rates.

3.1 Basic Environment

We assume that there are L workers each of whom are matched with L plants. A representative firm—henceforth, a multinational enterprise (MNE)—which possesses the plants produces goods through the supply chains. In other words, outputs produced at a plant j are used as inputs by a plant $j+1$ which performs a subsequent task. Total revenue of the MNE with a production supply chain of length n (i.e., a final good is manufactured by going through n production stages) is assumed to be

$$y(n) = n^{\alpha} l, \quad (0 < \alpha < 1), \tag{1}$$

where l is total labor employed. Labor is provided inelastically and wage rate is w which cannot be deferred. There is no physical capital. Cash flows in the supply chain are given as the following:

Table 1: Cash Flows of a Firm in the Supply Chain

		Production Stages					Cumulative
		1	2	$\cdots$	$n-1$	n	Cash Flow
Date t	1	$-\omega$					$-\omega$
	2	$-\omega$	$-\omega$				-3ω
	$\vdots$			$\ddots$			$\vdots$
	n	$-\omega$	$-\omega$	$\cdots$	$-\omega$	$-\omega$	$-\frac{n(n+1)}{2}\omega$
	$n+1$	$y(n)-\omega$	$-\omega$	$\cdots$	$-\omega$	$-\omega$	
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	

The first positive cash flow comes at date $n+1$ when the representative firm sells the final output for $y(n)$. Due to the discrepancy in timing when costs are incurred and payments from sales are made, the MNE should obtain outside funding—which is called working capital—to meet the expenses. This implies that the longer supply chains become, the greater amount of inventories in the form of intermediate outputs should be managed which, in turn, results in higher needs of working capital. Based on the cash flow in Table 1 the working capital which is needed to afford the accumulated wage costs from n production stages is

$$\frac{1}{2}n(n+1)w. \tag{2}$$

Since there are there are L/n plants in each stage, the aggregate financing requirement in the economy, K, thus can be denoted as

$$K = \frac{1}{2}(n+1)wL. \tag{3}$$

Equation (3) illustrates that the amount of working capital increases as the length of the supply chain becomes longer and/or the nominal wage payment becomes larger.

3.2 Production Fragmentation and the Environment

3.2.1 Offshoring and Value Generation

Based on the aforementioned basic structure of the supply chain, we now consider a case of production fragmentation in response to the change of credit costs (i.e., the rise of interest rates) and its impact on the environment.

To do so, we assume that the MNE optimally chooses the extent of offshoring production stages to foreign countries on which possess a comparative (or absolute) advantage in performing one specific task. To make the analysis simpler, we further assume that the total production stages are fixed to $\bar{n}$ (i.e., $n = \bar{n}$) which coincide with the number of locations where offshoring can take place. Given these conditions, total output (value-added) is generated by the following process:

$$\left(\sum_{i=1}^{\bar{n}} x_i\right)^{\alpha} \quad (0 < \alpha < 1), \tag{4}$$

where $x_i = 1 + b$ if the firm offshores the ith stage task abroad. Otherwise, $x_i = 1$. In other words, offshoring brings additional benefit, b, to the MNE in generating greater values since the production takes place at the optimal location.

Despite the benefit arising from offshoring activities exists, offshoring entails improved needs in working capital in the sense that it incurs delays until the offshored intermediate inputs are shipped to the destination.[13] For simplicity, we assume that one period of time is required for the transport which is equal to the time needed for the manufacturing processes at each stage of the supply chain.

We also assume that offshoring requires labor forces with the wage rate w and the working capital is met by borrowing money at the domestic interest rate r. Total production processes thus become $\bar{n} + s$ if the MNE decides to offshore s numbers of production stages. The total revenue generated per worker thus becomes

$$y(\bar{n}; s) = (\bar{n} + bs)^{\alpha}, \tag{5}$$

and the total working capital for the whole manufacturing processes after production fragmentation can be expressed as

$$K = \frac{\bar{n} + s + 1}{2} \omega L,$$

where L is the total endowment of labor force.

3.2.2 Emission generation

In addition to the value-added accumulated throughout the production, the MNE emits pollution as a byproduct. Total emissions depend on the amount of output, which is also affected by the extent of offshoring:

$$E = \sum_{i=1}^{\bar{n}} e_i \tag{6}$$

where $e_i = 1$ for a task i domestically conducted.

The effect of offshoring on the generation of emissions is a little nuanced. Since offshoring activities of the MNE incur international trade, we need to consider two channels through which the generation of air pollutant is affected: (a) forward participation (FP) and (b) backward participation (BP) of the MNE in the GVCs. The first channel refers to the extent that a country (the MNE in our context) exports domestically-produced intermediates abroad where the subsequent tasks take place. Thus, FP is directly and positively associated with domestic production activities which, in turn, has a positive effect in increasing pollution.

[13] See Bruno et al. (2018) for detail.

The second channel, on the other hand, indicates how much a country imports outsourced intermediates from its trade counterparts for the sake of exporting activities. BP incurs two offsetting effects on the environmental account. Since imported intermediate inputs are utilized for the domestic industrial production activities, BP of the MNE increases the total stock of air pollutants; however, at the same time, encouraged BP indicates that the MNE outsource pollution abroad which directly reduce air pollution.

Therefore, if the MNE decides to offshore s production stages to foreign countries with absolute advantage the total emissions generated in the home country is

$$\begin{aligned} E(\bar{n}; s) &= \bar{n} - s + \left(d^{FP} + d^{BP}\right) s, \\ &= \bar{n} + \left(d^{FP} + d^{BP} - 1\right) s \end{aligned} \tag{7}$$

where d^{FP} and $d^{BP} - 1$ respectively refers to the net marginal environmental damage arising from forward and backward participation of the MNE in the GVCs.[14] Since BP incurs counteracting forces in generating air pollutants, we introduce the following assumption since both FP and BP bring a strong momentum in lowering air quality via encouraged production activities:

Assumption. *The marginal effect of forward participation in generating emissions dominates that arising from backward participation.*

The assumption indicates that

$$d^{FP} + d^{BP} - 1 > 0,$$

which, in turn, implies that the greater extent of offshoring conducted the greater amount emissions are generated:[15]

$$\frac{\partial E}{\partial s} > 0.$$

This assumption is suggestively supported by the following empirical evidences which show the positive correlation between GVC participation and total greenhouse emissions.

[14] We assume that the marginal effects of FP and BP on the environment are constant regardless of the position of tasks in the vertical supply chain.

[15] This result is consistent with the fact that there is a positive correlation between GVC participation and total emissions. For example, China, India and the U.S. have intensively participated in the global production networks for the past few decades and they are the top three countries which emit the greatest amount of greenhouse gases.

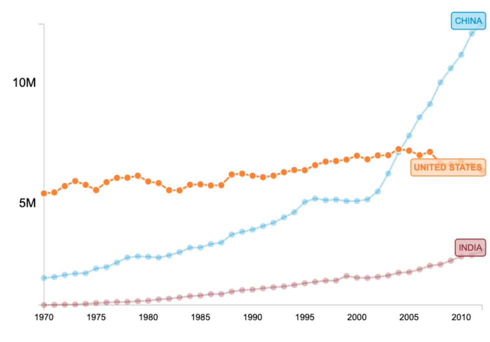
Figure 4: Trends in GVC Participation

(a) Indirect Domestic Content in Gross Export (b) Foreign value-added in Gross Export

Notes: These figures portray the extent of GVC participation of the U.S., China and India in terms of indirect domestic (IDC) and foreign value-added (FVA) content in their gross exports from 1995 to 2012. IDC and FVA respectively illustrate the forward and backward GVC participation of the countries. The unit of the measure in current US billion dollars. *Source:* The World Bank, TCdata360 (OECD-TiVA).

Figure 4 illustrates that the indirect domestic and foreign value-added contents of the U.S., China and India have commonly increased over the past decades. It implies that these countries have increasingly involved in global production sharing processes.

Figure 5: Trends in Total Greenhouse Gas Emissions



Notes: The figure describes the trends in total greenhouse gas emissions of the U.S., China and India which are the top three polluters in the world. The unit of the measure is kt in CO_2 equivalent. *Source:* The World Bank, TCdata360 (OECD-TiVA).

Figure 5 depicts the trends in greenhouse gas emissions of the three countries. It also shows an increasing trend in emissions over time. Since figures 4 and 5 do not necessarily imply a causal relationship between GVC participation—which is reflected by the extent of offshoring in our framework—and the level of emissions although a positive correlation between the two factors is shown, we introduce the aforementioned assumption at this stage and will show the causal relationships in the empirical section.

3.2.3 Credit costs, Offshoring and the Environment

In this section, we study the effect of credit costs on the extent of offshoring and on the environmental quality based on the discussion in the previous section.

Optimal offshoring. We can derive the optimal number of production stages which needs to be offshored from the profit maximization problem and a zero-profit condition:

$$s^* = \frac{2}{r}\left[\left[\left(\frac{r}{2\alpha b}\right)^{\alpha} w\right]^{\frac{1}{\alpha-1}} - 1\right] - (\bar{n}+1).$$

This result indicates that the rise in domestic credit costs discourages offshoring since it becomes more costly to finance working capitals:

$$\frac{\partial s^*}{\partial r} < 0.$$

Environmental consequences. Accounting for the discussions thus far the comparative static which illustrates the impact of the rise in domestic credit costs on total emissions can be expressed as

$$\frac{\partial E}{\partial r} = \underbrace{\frac{\partial E}{\partial s}}_{(+)} \cdot \underbrace{\frac{\partial s}{\partial r}}_{(-)} < 0,$$

which illustrates that a greater domestic credit costs results in the reduction of total emissions since it discourages the MNE to offshore production stages abroad. Hence, we introduce the first proposition as follows:

Proposition 1. *A greater domestic credit cost reduces emission of air pollutants since it reduces the participation of a country to the global value chain.*

The second environmental account we consider is emission intensities, which is defined as total emission per unit of value-added:

$$EI \equiv \frac{E}{Y(\bar{n};s)} = \frac{E}{y(\bar{n};s)L} = \frac{\bar{n} + \left(d^{FP} + d^{BP} - 1\right)s}{(\bar{n}+bs)^{\alpha} L}.$$

where $Y(\bar{n}; s)$ is the total value generated from the supply chain.[16] From the functional form of emission intensity, we can observe that the marginal effect of offshoring on emission is constant whereas that on total value is diminishing.

Thus, emission intensity varies by the relative significance of the two channels. From the following first-order condition we can compute the socially optimal extent of offshoring in minimizing emission intensity:

$$\frac{\partial EI}{\partial s} = \underbrace{\left(d^{FP} + d^{BP} - 1\right)(\bar{n} + bs)^{-\alpha} L^{-1}}_{\text{net effect of offshroing on emission}} - \underbrace{\left[\bar{n} + \left(d^{FP} + d^{BP} - 1\right) s\right](\bar{n} + bs)^{-\alpha-1} \alpha b L^{-1}}_{\text{net effect of offshoring on value generation}} = 0,$$

which yields

$$s^{**} = \frac{\left(d^{FP} + d^{BP} - 1 - \alpha b\right)\bar{n}}{\left[(\alpha - 1)\left(d^{FP} + d^{BP} - 1\right)\right] b}.$$

Assuming that there is a sufficient incentive to offshore—i.e., b is sufficiently large—we can derive a conclusion that

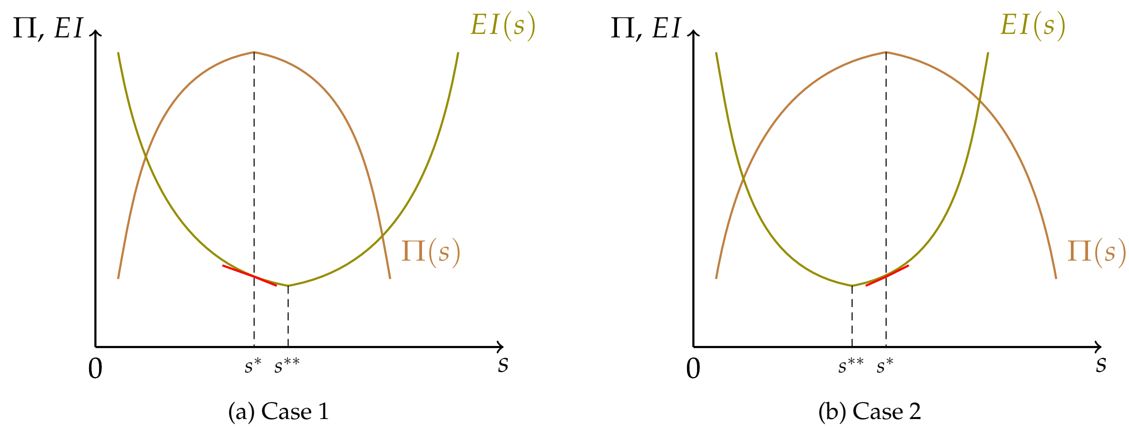
$$\frac{\partial EI}{\partial s} < 0 \quad \text{for} \quad \forall s < s^{**},$$
$$\frac{\partial EI}{\partial s} > 0 \quad \text{for} \quad \forall s > s^{**}.$$

In conjunction with the optimal extent of offshoring in maximizing profits, we can therefore consider the following two scenarios:

$$\frac{\partial EI}{\partial s} < 0 \quad \text{when} \quad s^{*} < s^{**},$$
$$\frac{\partial EI}{\partial s} > 0 \quad \text{when} \quad s^{*} > s^{**}.$$

[16] It is possible to argue that total value generated abroad cannot be accounted in domestic value-added. However, considering the fact that imported foreign value-added is again used for domestic production, we consider domestically produced intermediate inputs embed foreign value-added, which in turn enable us to simply calculate emission intensity by the division of total emission with the total value-added regardless of the production origin.

Figure 6: Production Fragmentation and Emission Intensity



Notes: This figure describes the marginal effect (the red line) of offshoring on emission intensity under two scenarios.

Figure 6 illustrates the dynamics of emission intensity in response to the extent of offshoring. The first case shows that offshoring helps reduce emission intensity if the profit maximizing level of offshoring is less than environmentally optimal level of offshoring. The second case, on the other hand, shows the opposite situation where a greater extent of offshoring deteriorates the environment when the MNE does not internalize the environmental externality and thus the profit-maximizing offshoring level exceeds socially desirable level of offshoring in preserving environmental quality.

The comparative statics below incorporate these scenarios and show the effect of greater domestic credit costs on emission intensity:

$$\frac{\partial EI}{\partial r} = \begin{cases} \underbrace{\frac{\partial EI}{\partial s}}_{(-)} \cdot \underbrace{\frac{\partial s}{\partial r}}_{(-)} > 0 & \text{if} \quad s^* < s^{**}, \\ \underbrace{\frac{\partial EI}{\partial s}}_{(+)} \cdot \underbrace{\frac{\partial s}{\partial r}}_{(-)} < 0 & \text{if} \quad s^* > s^{**}. \end{cases}$$

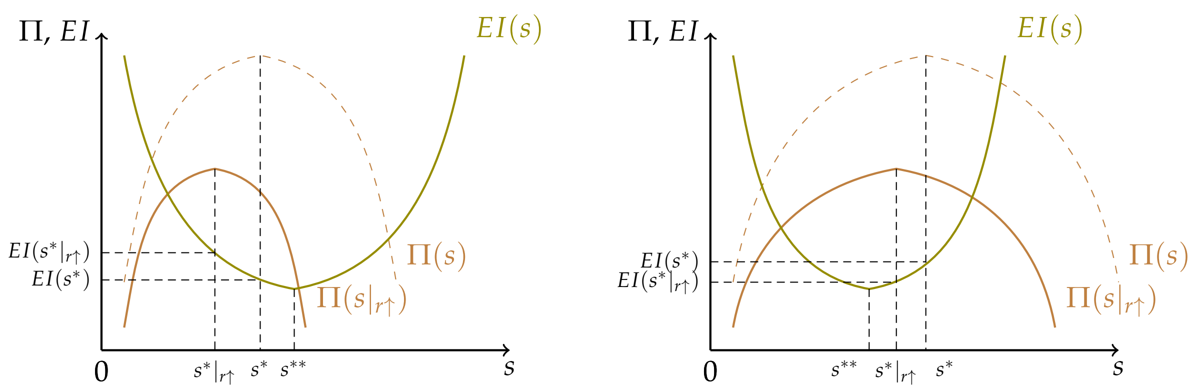
From the results we derive thus far, we introduce the following two propositions:

Proposition 2. *A greater domestic credit cost raises emission intensities when the profit-maximizing level of offshoring is less than environmentally optimal extent of offshoring.*

Proposition 3. *A greater domestic credit cost reduces emission intensities when the profit-maximizing* *level of offshoring is greater than environmentally optimal extent of offshoring.*

Figure 7 portrays the comparative statics illustrated above. Since we have an theoretical ambiguity in the direction of emission intensity in response to the rise in domestic credit costs, it now becomes an empirical question to reveal a causal relationship of the value of domestic currency and environmental consequences.

Figure 7: Differential Effect of Credit Costs on Emission Intensity



(a) Case 1 (b) Case 2

Notes: This figure describes the effect of domestic credit costs on the variation of emission intensities under two scenarios.

3.2.4 Policy Implications

The results discussed so far possess interesting and important policy implications. Accounting for the fact that a monetary policy can be one of the determinants of domestic credit costs (Gertler and Karadi, 2015), the model tells us that a monetary policy which raises domestic credit costs can be effective in reducing the total stock of air pollutant. However, we need to remember that emission decreases due to discouraged economic activities because of high credit costs.

The effect on emission intensity is theoretically mixed. Case 1 describes a case where the marginal effect of offshoring on total value generated is sufficiently large enough to outweigh that on the generation of emissions. Thus, a contractionary monetary policy inducing greater domestic credit costs may escalate emission intensities since it strictly discourages firms' offshoring activities. In this case, therefore, an expansionary monetary policy can help improve environmental quality by lowering emission intensity. However, if the monetary policy overly encourages offshoring so that the marginal economic gain is outweighed by the marginal environmental damage arising from offshoring, lowering credit costs can be detrimental in lowering emission intensities.

Case 2 illustrates the opposite situation. If the marginal benefit of offshoring in generating total economic value rapidly diminishes, a contractionary monetary policy which discourages firms' offshoring activities may lower emission intensities. However, this policy may also be harmful in improving environmental quality if it overly discourages firms' offshoring decisions.

In the next section, we introduce the empirical identification strategy which supports the causal effect of domestic credit costs—which are influenced by monetary policy—on the environmental accounts we have found theoretically.

4 Empirical Identification

4.1 Methods

The Vector Autoregression (VAR) helps analyze the dynamic response of the variables of interest to external shocks. A representative structural VAR can be expressed as

$$By_t = C(L)y_t + \varepsilon_t, \tag{8}$$

where y_t is an $n \times 1$ vector of endogenous variables,[17] B and C are matrices of the estimated coefficients,[18] and L is a lag operator.[19] A $n \times 1$ vector of structural shocks denoted as ε_t are defined as follows:

$$\varepsilon_t \sim i.i.d.\ N(0, \Omega), \text{ where } \Omega = I_n. \tag{9}$$

Our goal is to estimate the dynamic causal effect of ε_t on y_{t+h}:

$$\frac{\partial y_{t+h}}{\partial \varepsilon_t}, \ h = 1, 2, 3... \tag{10}$$

In order to identify the impulse response of y_t with respect to ε_t, we need to transform Equation

[17]VAR relates variables in vector y to their past values, y_{t-i} where $i = 1, 2, ...$

[18]A structural form is represented by an economic theory or prior beliefs. However, parameters in B and C are not identifiable without additional restrictions, which is why we transform the structural form to the reduced form.

[19]In a time series analysis, a lag operator is used for a convenient representation of lag variables. For example, $C(L) = C_1L + C_2L + ... + C_pL$ for VAR(p). Then, $C(L)y_t = C_1y_{t-1} + C_2y_{t-2} + ... + C_py_{t-p}$.

(8) to a reduced form:[20]

$$y_t = A(L)y_t + v_t, \tag{11}$$

where $A(L) = B^{-1}C(L) = A_1L + A_2L^2 + \cdots + A_iL^i$, and i is the number of lag. v_t is the reduced form shock, given by

$$v_t = S\varepsilon_t, \tag{12}$$

with $S = B^{-1}$. The variance-covariance matrix, Σ, of an error term in Equation (11) is

$$\Sigma = E[v_t v_t'] = E[SS']. \tag{13}$$

Then, the following equation allows us to identify the impulse response to a structural shock:

$$y_t = A(L)y_t + S\varepsilon_t. \tag{14}$$

The Cholesky decomposition is a common identification scheme which imposes coefficient restrictions on S: it assumes that a variable does not depend contemporaneously on the variables ordered after in the vector y_t.[21] Under this assumption, therefore, we are not able to capture contemporaneous responses among variables of our interest such as industrial production, international trade and the generation of emissions which are very likely to be influenced by one another. To this end, instead of adopting a conventional Cholesky decomposition method imposing ordering conditions, we exploit an external instrument to identify S (Mertens and Ravn, 2013) which allows for the simultaneous effects among variables.

Let z_t be a $k \times 1$ vector of instrument variables. Then, valid instrument variables (IV), z_t, should satisfy the following conditions:

$$E[z_t \varepsilon_t^{p\prime}] = \Phi, \tag{15}$$

$$E[z_t \varepsilon_t^{q\prime}] = 0, \tag{16}$$

where ε_t^p is the $k \times 1$ shock of interest vector and ε_t^q denotes all other $(n-k) \times 1$ vector of shocks.

[20] In this study, y_t contains exchange rates, trade- and emission-related variables.

[21] The Cholesky decomposition allows for causal ordering by transforming positive definite symmetric matrix into the product of a lower triangular matrix and its conjugate transpose. This implies that a shock can only have a contemporaneous effect on the variables below itself in the matrix.

The relevance condition in Equation (15) means that the instrument should be correlated with the endogenous shock variable of our interest, ε_t^p. The exogeneity condition in Equation (16) implies that the instrument affects the dependent variable only via ε_t^p and is orthogonal to other shock variables, ε_t^q. With z_t which satisfies these conditions, the two-stage least squares (2SLS) allows for the estimates of S (Gertler and Karadi, 2015).[22] Then, with the estimates of S, we can identify the dynamic causal effect of the structural shocks (ε_t) on y_t.

4.2 Data

We use monthly-level data of real effective exchange rates (REER), import, export, industrial production, CO_2 emissions, and emission intensity of the U.S. from August 2001 to August 2017 as the endogenous variables (y_t).[23] REER reflects global credit conditions affecting international trade activities. For example, an appreciation of U.S. dollars is associated with a lose of price competitiveness of exported U.S. commodities. Our data allow us to study how REER affects GVC activities of the U.S. and, as a consequence, influences on the national environmental accounts such as total emissions and emission intensities. In order to consider forward and backward linkages of the U.S. in GVCs, we also derive monthly indirect domestic value-added contents (IDC) and foreign value-added contents in gross export (FVA) during January 2002 to December 2011 from OECD-TiVA database.[24]

To identify the dynamic causal effect of REER on the domestic environmental quality, we employ a monetary policy surprise as an external instrument for the real effective exchange rate since monetary policy is closely associated with the movement of the real effective exchange rates (Baldwin and Krugman 1989; Bruno et al. 2018) while it affects emissions only through the variations

[22]The intuition is as follows: First, the reduced form VAR in Equation (11) provides estimates of v_t. Let v_t^p be the residual which corresponds to ε_t^p in Equation (12). Likewise, let v_t^q be the residual which connects to ε_t^q. Next, the regression of z_t on v_t^p yields $\widehat{v_t^p}$. Then, the regression of v_t^p on $\widehat{v_t^p}$ allows for estimating the elements in S that are related to the structural shock ε_t^p.

[23]We obtain REER, international trade and industrial production data (constant 2010 dollars, seasonality adjusted) from the Global Economic Monitor provided by the World Bank. Monthly data on CO_2 emissions by broadly defined industrial sectors from energy consumption are from the U.S. Energy Information Administration (EIA) and emission intensity is calculated by the authors.

[24]Here, due to a lack of monthly data availability, we impose an assumption that the forward and backward participation rates—which are respectively defined as the share of domestic value-added used for foreign exports and foreign value-added in gross exports—do not vary across months within a year. We multiply these rates to monthly-varying gross exports in order to derive proxies of monthly-level indirect domestic contents and foreign value-added contents in gross exports.

of real effective exchange rates. To this end, the monetary policy surprise satisfies both relevance and exogenous conditions described in equations (15) and (16).

The monetary policy surprise, FF_t, is defined as changes in the expectation for the Fed Funds rate between 10 minutes before, $Expected_{t,-10}$, and 20 minutes, $Expected_{t,+20}$, after the FOMC announcement:

$$FF_t = (Expected_{t,+20} - Expected_{t,-10}). \tag{17}$$

To calculate $Expected_{t,-10}$ and $Expected_{t,+20}$, we exploit changes in the Fed Funds Futures rate between 10 minutes before and 20 minutes after the FOMC decision. Within a 30-minute window, the monetary policy surprise, FF_t, measures the unanticipated component of the Fed's decision on the current Fed Funds rate target (Kuttner, 2001). If there is no surprise in the Fed's decision, FF_t is zero, because $Expected_{t,-10}$ and $Expected_{t,+20}$ have the same value.

For each FOMC announcement from August 2001 to August 2017, we calculate the monetary policy surprise.[25] In general, the FOMC holds eight regular scheduled meetings each year. This implies that there are no regular meetings in four months a year. To extend the monetary policy surprises on each FOMC meeting day to the monthly level data, we borrow a method from Gertler and Karadi (2015). For each day of month, we accumulate the surprises on FOMC date during the last 31 days. By averaging these monthly surprises across each day of the month, we obtain monthly U.S. monetary policy surprises.

5 Results

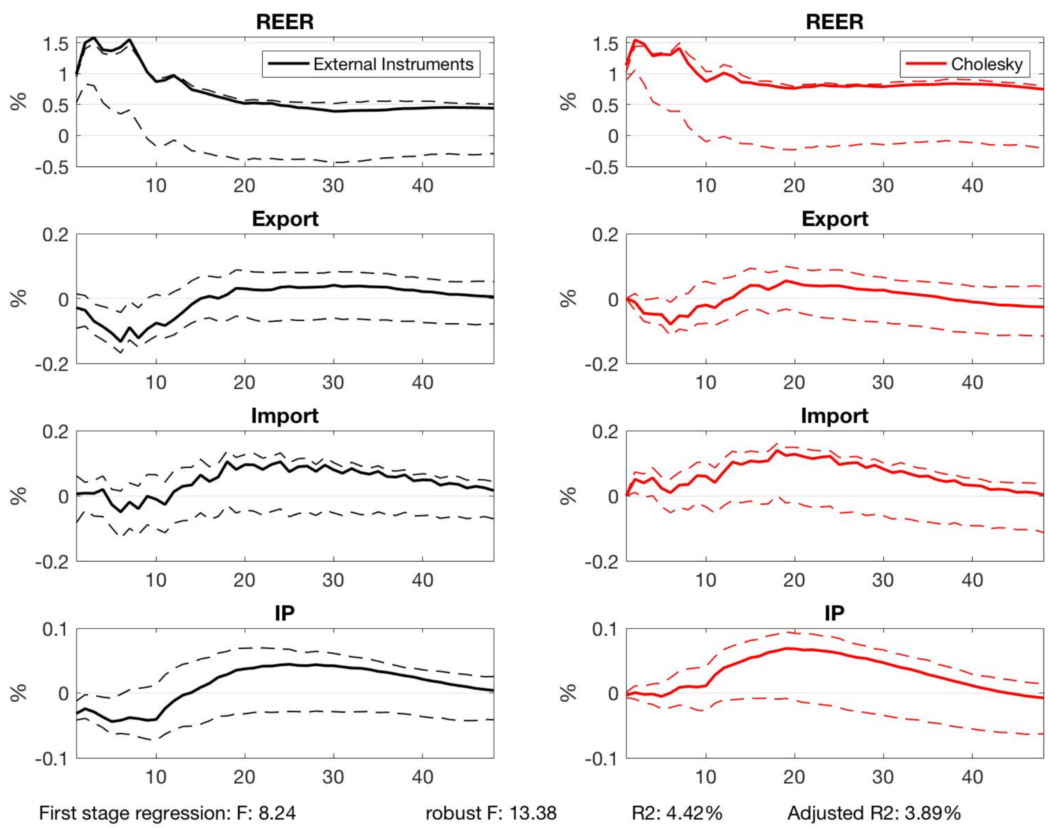
In this section, we empirically demonstrate the impact of credit costs on the environmental accounts by implementing the proxy-VAR method using monetary policy surprises as an external instrument. We start with the comparison of the proxy-VAR with a conventional Cholesky decomposition in order to demonstrate the necessity of using an external instrument. As we have discussed, the external instrument method allows for contemporaneous responses among variables in contrast to Cholesky decomposition method.

[25]Our data set covers 130 FOMC decisions which were made in regular and irregular meetings.

5.1 Proxy-VAR vs. Cholesky Decomposition

Following Gertler and Karadi (2015), we compare results from proxy-VAR (left panels) with those from the standard Cholesky identification (right panels) as shown in Figure 8. We can observe that a robust F-value of 13.3 ensures the validity of monetary policy surprise as an external instrument.[26]

Figure 8: REER Shock with External Instrument



Notes: The left and right panels show an external instrument case and Cholesky identification case, respectively. The dotted line represents 95 percent confidence interval, calculated by bootstrapping methods. We report a robust *F*-value to address a possible heteroskedasticity.

It is shown in both identification strategies that a surprising monetary tightening by a one standard deviation leads to a 1 percent increase in real effective exchange rate, which is statisti-

[26]According to Staiger and Stock (1997) and Stock and Yogo (2005), a F-value can be used to find weak instruments. For example, a F-value should be greater than 10 to ensure the maximum bias in IV estimators to be less than 10 percent under the assumption of conditionally homoscedastic serially uncorrelated errors. However, Olea and Pflueger (2013) point out that a homoscedastic F-static is not applicable for non-homescedastic case. So we also provide non-homoscedastic robust F-statistics.

cally significant. This indicates that monetary tightening leads to an intensified money inflow to the U.S., which in turn allows for the appreciation of dollar-value. Exports consequently decline because of the loss in trade competitiveness, which is consistent with a conventional trade theory.

External instrument and Cholesky schemes provide different responses of imports to the REER shock. External instrument approach indicates that imports decline initially and then reverts back as time proceeds. Despite the statistical insignificance, we believe that this pattern better reflects the inter-linkage of the U.S. to the rest of the world via global value chains. When production processes are highly fragmented, the discouraged exports would lead to lower demands for intermediate inputs outsourced abroad which accordingly decreases gross import levels. On the other hand, the Cholesky identification shows that higher dollar-value leads to higher imports. This implies that the contemporaneous relationship between the exports and imports are limited under the Cholesky scheme.

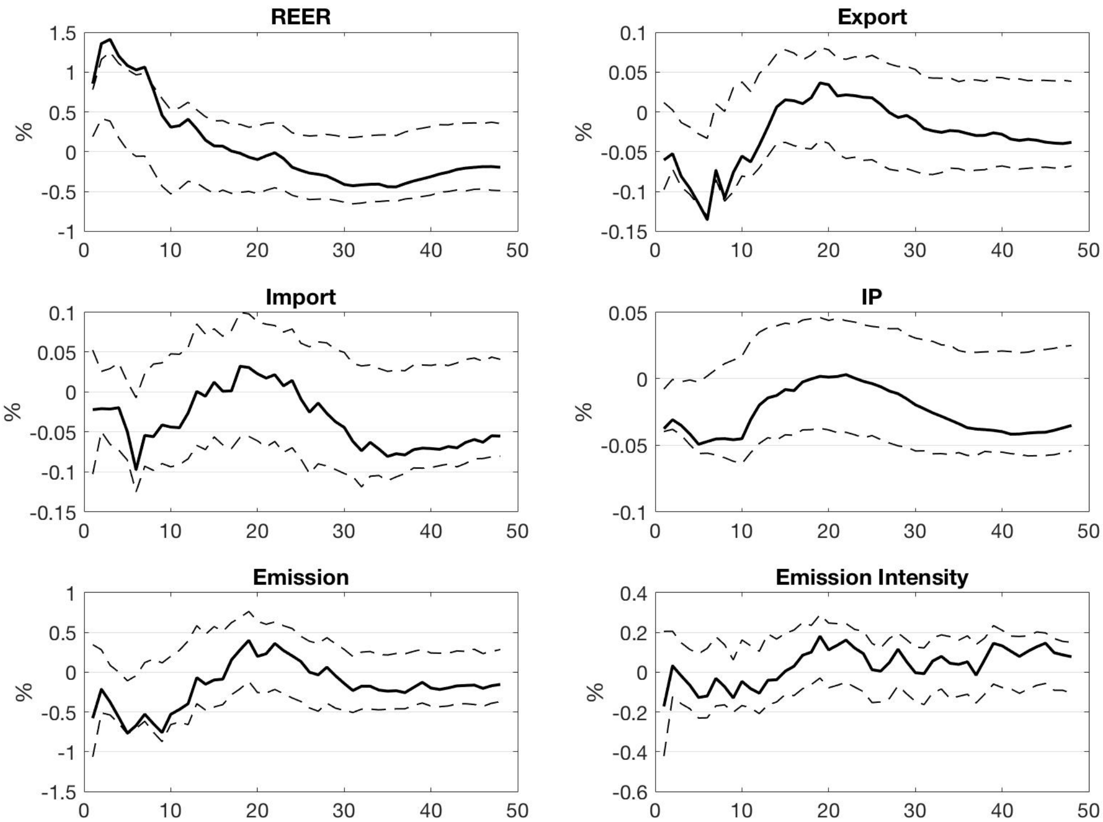
We also find that a tightening monetary policy leads to a significant slowdown in industrial production, which is also consistent with existing theory. In contrast to the external instrument approach, however, the Cholesky identification provides no meaningful response in industrial production. Given the timing restriction under the Cholesky, the industrial production cannot affect other variables simultaneously. This implies that the standard Cholesky scheme may not be suitable to apply in our analysis because domestic environmental accounts are contemporaneously related to production activities. To this end, we decide to use the proxy-VAR to examine how a surprising monetary policy raising domestic credit costs (and, at the same time, appreciate domestic currency value) affects environmental quality by taking the simultaneous effects among variables into account.

Next, we additionally consider emissions and emission intensity to study how these factors are associated with a monetary policy shock (and REER dynamics).

5.2 Gross Exports/Imports and the Environment

As shown in Figure 9, we investigate how the external monetary policy shock influences on emissions and emission intensities by altering gross exports and imports which do not specifically address intermediate input trade via supply chains.

Figure 9: The Effect of Monetary Policy Shock on Environmental Accounts



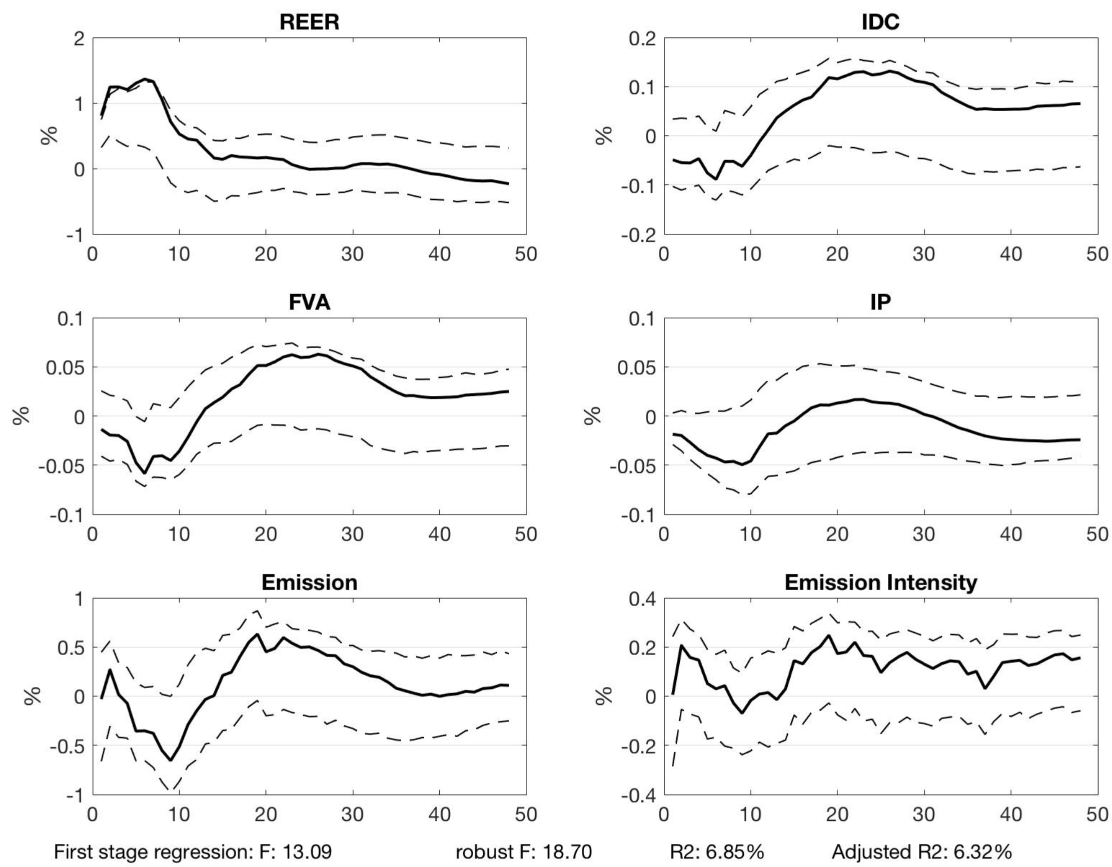
First stage regression: F: 6.59 robust F: 10.17 R2: 3.57% Adjusted R2: 3.03%

Notes: We use monetary policy surprises as an external instrument to estimate impulse responses. The dotted line represents 95 percent confidence interval, calculated by bootstrapping methods. We report a robust *F*-value to address a possible heteroskedasticity.

With a monetary policy surprises as an instrument, a robust *F*-value of 10.17 avoids a weak instrument problem. For a surprising monetary tightening by a one standard deviation, there is a significant rise in REER. Due to an appreciation of U.S. dollars compared to a basket of currencies of U.S. trade partners, gross exports decrease, which also leads to the lower level of imports. Domestic industrial production also drops accordingly. Overall, the responses confirm the conventional view about a relationship between REER and real variables.

When we broadly define gross exports and imports as indicators of international trade through the global value chains, environmental consequences of monetary tightening seem unclear. We can observe that both CO_2 emissions and emission intensities drop in response to a monetary tightening; however, both results show a very weak statistical significance. We thus narrow down our focus on addressing intermediate input trade and its environmental consequences in the next section.

Figure 10: The Effect of Monetary Policy Shock on Environmental Accounts via GVC



Notes: We use monetary policy surprises as an external instrument to estimate impulse responses. The dotted line represents 95 percent confidence interval, calculated by bootstrapping methods. We report a robust *F*-value to address a possible heteroskedasticity.

5.3 Intermediate Input Trade and the Environment

To account for intermediate input trade via the supply chains, we focus on both domestic value-added associated with intermediate input production and foreign-produced inputs imported from abroad for exports.

Figure 10 shows how the macroeconomic impulse propagates through the channel of global value chains and ultimately affects environmental accounts in the U.S. In response to a surprising monetary tightening which represents in higher domestic credit costs, the indirect domestic value-added in gross export (IDC) promptly diminishes. This represents that the forward linkage of the U.S. in the global value chain weakens due to stronger dollars since the appreciation of domestic currency lowers the competitiveness of a country in exporting activities.

The weakened forward linkage subsequently affects the backward linkage of the U.S. We can observe that foreign value-added content in gross export (FVA) shrinks after the reduction in IDC. This suggests that importing activities are strongly affected by exporting decisions of firms particularly in the global production networks.[27] These facts are consistent with a theoretical finding that greater domestic credit costs are associated with the reduction in offshoring activities, which in turn implies that the number of foreign trade counterparts diminishes as a consequence of surprising monetary policy—the extensive margin of trade.[28]

In a highly globalized world, domestic industrial production is positively correlated with international trade activities. We can verify that industrial production (IP) depicts similar patterns as those of IDC and FVA. In other words, contractionary monetary policy which induces higher domestic credit costs and stronger dollars in the foreign exchange market slows down the economy. This effect causes the reduction in total emissions which is also consistent with the prediction of the model described earlier.[29]

In contrast to the response of emissions with respect to monetary policy surprises, emission intensity increases after the shock and the effect is statistically significant. Put differently, stronger dollar causes a greater generation of air pollutants per value-added (i.e., each output is produced in a "dirtier" way). As described in the first case in Figure 7, this is because escalated domestic credit costs discourage firms to offshore production tasks abroad. From the conceptual framework described earlier, we can infer that the U.S. federal government can induce "cleaner" manufacturing processes by encouraging firms to offshore production stages abroad via expansionary monetary policy.

This finding is novel in the environment-trade literature because it shows a new channel that the domestic environmental quality can be improved by international trade when it is combined

[27] Blaum (2019) also focuses on a similar empirical finding that the aggregate share of imported inputs increases in a large devaluation since importers are also exporters in the modern global economy integrated by the value chains.

[28] We are also able to see that the response of FVA in regards to monetary surprises is less elastic in terms of magnitude than that of IDC. This finding is in line with conventional trade theory which predicts that importing activities are encouraged due to stronger dollars—the intensive margin of trade.

[29] Although there is an upward trend in total carbon emission shortly after the monetary policy shock, the trend is statistically insignificant and still the overall pattern is downward sloping.

with macroeconomic policies.[30]

6 Discussion

Being aware of environmental externality of monetary policies particularly through the global value chains is crucial because it conveys several important policy suggestions.

First, implementing a contractionary monetary policy can be one of the second-best options that can be considered alongside the first-best environmental policies if policymakers prioritize the reduction of total stock of pollutants as public health is at risk due to high concentration of ambient toxins in the air.[31] Under a situation of this kind, a monetary tightening has an effect of raising financing costs of multinationals which, in turn, reduces GVC participation and thus the total trade volume both in extensive and intensive margins. The diminished scale of production consequently lowers the level of emissions.[32]

However, an expansionary monetary policy can be an ideal policy option if improving environmental quality and encouraging economic growth are the dual-goal of the government. The expansionary monetary policy can be beneficial in lowering emission intensities—not emissions per se—since it encourages multinationals to participate in the GVCs which, in turn, enable them to significantly improve their productivity and, at the same time, restrain the increase of emissions from outsourcing pollution abroad.

Second, we can also infer that governments can combine monetary and environmental policies to incentivize multinationals to offshore productions abroad to maximize the effect of an expansionary monetary policy on reducing emission intensities.[33] Furthermore, we can envision that

[30]Previous studies have mainly focused on changes in industrial composition via heterogeneous firms' entry/exit and innovation either encouraged by environmental regulations or escalated competition as the main channels that international trade improves emission intensities.

[31]For example, China has been experiencing frequent smog and high concentration of particulate matters in major cities for the past two decades which brought health issues (such as an higher infant mortality rate and/or respiratory and cardio-vascular diseases) as one of the main concerns of Chinese government. Due to data availability, we mainly focus on emissions in carbon dioxide which is regarded as a global pollutant. However, our framework can be extensively applied to a variety of local air pollutant such as sulfur dioxide, nitrogen oxide and particulate matters which are associated with intermediate input trade activities along the global value chains. If reducing the total stock of air pollutant causing respiratory and cardiovascular disease is the primary object of the government, implementing contractionary monetary policies can complement environmental regulations and improve public health.

[32]Similarly, Bombardini and Li (2020) empirically show the positive effect of exports—which are related to domestic industrial productions—on Chinese infant mortality rate. However, they do not capture the role of monetary policies affecting GVCs and the environment.

[33]There are many papers focusing on firms' behavior of outsourcing pollution abroad due to stringent domestic

the role of monetary policy as an indirect policy tool of improving environmental quality can be powerful especially when the effects of environmental regulations are limited such as in the critical economic downturns like 2008-2009 financial crisis and COVID-19 pandemic crisis. Accounting for the fact that the global value chains have been significantly disrupted either by demand and/or supply shocks during these crises, this paper conveys a message that reestablishing and stabilizing the global production networks are the prerequisites in order for the effectiveness of monetary policy as an instrument of saving the environment.

7 Conclusion

In this paper, we have addressed the causal effect of a contractionary monetary policy on the domestic environmental accounts particularly through the channel of GVCs. We find that the participation of multinational firms' to the GVCs via offshoring intermediate tasks abroad is discouraged because of the monetary policy raising domestic credit costs. As a consequence, the total volume of emissions decreases while the amount of pollutants per value-added increases due to a significant reduction in industrial production. The externality of monetary policies on the domestic environmental quality conveys a message that governments are able to consider monetary policies as a supplement of environmental regulations in addition to the main purpose of economic stabilizer.

The findings we convey should be seen in light of some limitations. In contrast to financial high-frequency data such as real effective exchange rates and Fed funds rates, international trade data associated with GVCs are limited to the annual level. To this end, we impose an assumption that the monthly backward and forward linkages of the U.S. remain constant within a year. To better account for the environmental externality of macroeconomic shocks via GVCs, we hope that more detailed analyses can be conducted in the near future with alternative trade and GVC-related variables that can better link high-frequent changes occurring in the financial sector.

environmental regulations: so called Pollution Haven Hypothesis. See Cherniwchan et al. (2016) for detailed summary.

References

Antweiler, Werner, Brian R Copeland, and M Scott Taylor, "Is Free Trade Good for the Environment," *American Economic Review*, 2001, *91* (4), 877.

Anzuini, Alessio, Marco J Lombardi, and Patrizio Pagano, "The Impact of Monetary Policy Shocks on Commodity Prices," 2012.

Asteriou, Dimitrios, Kaan Masatci, and Keith Pılbeam, "Exchange Rate Volatility and International Trade: International Evidence From the MINT Countries," *Economic Modelling*, 2016, *58*, 133–140.

Bacchetta, Philippe and Eric Van Wincoop, "Does Exchange-Rate Stability Increase Trade and Welfare?," *American Economic Review*, 2000, *90* (5), 1093–1109.

Baldwin, Richard and Paul Krugman, "Persistent Trade Effects of Large Exchange Rate Shocks," *The Quarterly Journal of Economics*, 1989, *104* (4), 635–654.

Baldwin, Richard E and Chiara Ravetti, "Emissions, Exporters and Heterogeneity: Asymmetric Trade Policy and Firms Selection," Technical Report, The Graduate Institute of International and Development Studies 2014.

Barrows, Geoffrey, Hélene Ollivier et al., "Emission Intensity and Firm Dynamics: Reallocation, Product mix, and Technology in India," *Work. Pap., Grantham Inst., London Sch. Econ*, 2016.

Bjørnland, Hilde C, "Monetary Policy and Exchange Rate Overshooting: Dornbusch Was Right After All," *Journal of International Economics*, 2009, *79* (1), 64–77.

Blaum, Joaquin, "Global Firms in Large Devaluations," *Unpublished Manuscript, Brown University*, 2019.

Bombardini, Matilde and Bingjing Li, "Trade, Pollution and Mortality in China," *Journal of International Economics*, 2020, p. 103321.

Bruno, Valentina, Se-Jik Kim, and Hyun Shin, "Exchange Rates and the Working Capital Channel of Trade Fluctuations," in "AEA Papers and Proceedings," Vol. 108 2018, pp. 531–36.

Bussière, Matthieu, Guillaume Gaulier, and Walter Steingress, "Global Trade Flows: Revisiting the Exchange Rate Elasticities," *Open Economies Review*, 2020, pp. 1–54.

Chen, Natalie and Luciana Juvenal, "Quality, Trade, and Exchange Rate Pass-Through," *Journal of International Economics*, 2016, *100*, 61–80.

Cherniwchan, Jevan, "Trade Liberalization and the Environment: Evidence From NAFTA and US Manufacturing," *Journal of International Economics*, 2017, *105*, 130–149.

_ , Brian R Copeland, and M Scott Taylor, "Trade and the Environment: New Methods, Measurements, and Results," *Annual Review of Economics*, 2016, (0).

Cole, Matthew A, Robert RJ Elliott, Okubo Toshihiro, Liyun Zhang et al., "The Pollution Outsourcing Hypothesis: An Empirical Test for Japan," Technical Report No. 17096 2017.

Cui, Jingbo, Harvey Lapan, and GianCarlo Moschini, "Productivity, Export, and Environmental Performance: Air Pollutants in the United States," *American Journal of Agricultural Economics*, 2015, *98* (2), 447–467.

Dean, Judith M and Mary E Lovely, "Trade Growth, Production Fragmentation, and China's Environment," in "China's growing role in world trade," University of Chicago Press, 2010, pp. 429–469.

Dietzenbacher, Erik, Jiansuo Pei, and Cuihong Yang, "Trade, Production Fragmentation, and China's Carbon Dioxide Emissions," *Journal of Environmental Economics and Management*, 2012, *64* (1), 88–101.

Dornbusch, Rudiger, "Expectations and Exchange Rate Dynamics," *Journal of Political Economy*, 1976, *84* (6), 1161–1176.

Eichenbaum, Martin and Charles L Evans, "Some Empirical Evidence on the Effects of Shocks to Monetary Policy on Exchange Rates," *The Quarterly Journal of Economics*, 1995, *110* (4), 975–1009.

Forbes, Kristin, Ida Hjortsoe, and Tsvetelina Nenova, "The Shocks Matter: Improving Our Estimates of Exchange Rate Pass-Through," *Journal of International Economics*, 2018, *114*, 255–275.

Forslid, Rikard, Toshihiro Okubo, and Karen Helene Ulltveit-Moe, "International Trade, CO2 Emissions and Heterogeneous Firms," 2011.

_ , _ , and _ , "Why Are Firms that Export Cleaner? International Trade, Abatement and Environmental emissions," *Journal of Environmental Economics and Management*, 2018, *91*, 166–183.

Georgiadis, Georgios, "Determinants of Global Spillovers From US Monetary Policy," *Journal of International Money and Finance*, 2016, *67*, 41–61.

Gertler, Mark and Peter Karadi, "Monetary Policy Surprises, Credit Costs, and Economic Activity," *American Economic Journal: Macroeconomics*, 2015, *7* (1), 44–76.

Grether, Jean-Marie, Nicole A Mathys, and Jaime de Melo, "Scale, Technique and Composition Effects in Manufacturing SO2 Emissions," *Environmental and Resource Economics*, 2009, *43* (2), 257–274.

Héricourt, Jérôme and Sandra Poncet, "Exchange Rate Volatility, Financial Constraints, and Trade: Empirical Evidence From Chinese Firms," *The World Bank Economic Review*, 2015, *29* (3), 550–578.

Holladay, J Scott, "Exporters and the Environment," *Canadian Journal of Economics/Revue canadienne d'économique*, 2016, *49* (1), 147–172.

Iacoviello, Matteo and Gaston Navarro, "Foreign Effects of Higher US Interest Rates," *Journal of International Money and Finance*, 2019, *95*, 232–250.

Kreickemeier, Udo and Philipp M Richter, "Trade and the Environment: The Role of Firm Heterogeneity," *Review of International Economics*, 2014, *22* (2), 209–225.

Kuttner, Kenneth N, "Monetary Policy Surprises and Interest Rates: Evidence From the Fed Funds Futures Market," *Journal of Monetary Economics*, 2001, *47* (3), 523–544.

Levinson, Arik, "Technology, International Trade, and Pollution From U.S. Manufacturing," *The American Economic Review*, 2009, *99* (5), 2177–2192.

Li, Xiaoyang and Yue M Zhou, "Offshoring Pollution While Offshoring Production?," *Strategic Management Journal*, 2017, *38* (11), 2310–2329.

Liu, Hongxun, Jianglong Li, Houyin Long, Zhi Li, and Canyu Le, "Promoting Energy and Environmental Efficiency Within a Positive Feedback Loop: Insights from Global Value Chain," *Energy Policy*, 2018, *121*, 175–184.

Martin, Leslie A, "Energy Efficiency Gains from Trade: Greenhouse Gas Emissions and India's Manufacturing Sector," *Mimeograph, Berkeley ARE*, 2011.

Meng, Bo, Glen Peters, and Zhi Wang, "Tracing CO2 Emissions in Global Value Chains," IDE Discussion Papers 486, Institute of Developing Economies, Japan External Trade Organization(JETRO) January 2015.

Mertens, Karel and Morten O Ravn, "The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States," *American Economic Review*, 2013, *103* (4), 1212–47.

Olea, José Luis Montiel and Carolin Pflueger, "A Robust Test for Weak Instruments," *Journal of Business & Economic Statistics*, 2013, *31* (3), 358–369.

Rey, Hélène, "International Channels of Transmission of Monetary Policy and the Mundellian Trilemma," *IMF Economic Review*, 2016, *64* (1), 6–35.

Shapiro, Joseph S and Reed Walker, "Why is Pollution from US Manufacturing Declining? The Roles of Environmental Regulation, Productivity, and Trade," *American Economic Review*, 2018, *108* (12), 3814–54.

Staiger, Douglas and James H Stock, "Instrumental Variables Regression with Weak Instruments," *Econometrica*, 1997, *65* (3), 557–586.

Stock, James and Motohiro Yogo, "Asymptotic distributions of instrumental variables statistics with many instruments," *Identification and inference for econometric models: Essays in honor of Thomas Rothenberg*, 2005, pp. 109–120.

Stock, James H and Mark W Watson, "Identification and Estimation of Dynamic Causal Effects in Macroeconomics Using External Instruments," *The Economic Journal*, 2018, *128* (610), 917–948.

Wei, Shang-Jin and Yinxi Xie, "Monetary Policy in an Era of Global Supply Chains," *Journal of International Economics*, 2020, p. 103299.