Journal of Cleaner Production 423 (2023) 138730

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

# Can the Federal Reserve save the environment?

Kyoung-Gon Kim [a], Doyoung Park [b,*]

[a] Hanbat National University, Republic of Korea
[b] University of Arkansas, Fayetteville, United States of America

ARTICLE INFO

Handling Editor: Giovanni Baiocchi

*JEL classification:*
E52
F18
F41
Q53

*Keywords:*
Domestic credit cost
Emission
Emission intensity
Global value chain
Monetary policy
Real effective exchange rate

ABSTRACT

This study examines the environmental effect of monetary policy, particularly within the framework of global value chains (GVCs). Given the escalating climate concerns and the urgent need for sustainable solutions, it is crucial to investigate the environmental consequences of monetary policy decisions which directly influence domestic production and international input-sourcing activities. As the monetary policy is likely to be associated with a variety of economic factors influencing environmental outcomes, it is critical to introduce an exogenous shock that reflects variations in monetary policies to derive unbiased causal estimates. We thus adopt a proxy-vector autoregression (VAR) approach with U.S. monetary policy surprise as an exogenous instrument. We uncover compelling evidence that one standard deviation of contractionary monetary policy surprise leads to a reduction in overall emissions by approximately 0.5 percent. However, the more significant and concerning result is the observed rise in *emission intensities* by 0.2 percent. We highlight the key mechanism underlying this outcome: higher domestic credit costs discourage firms from effectively outsourcing production tasks abroad, thereby increasing the generation of air pollutants per unit of output arising from reduced production efficiency. The identification of a previously unrecognized environmental externality calls for a reevaluation of policy approaches and underscores the importance of integrating environmental considerations into monetary policy frameworks.

## 1. Introduction

### 1.1. Background and motivation

The recent 6th Assessment Report of the United Nations' Intergovernmental Panel on Climate Change (IPCC) reinforces the urgent need to reduce greenhouse gas (GHG) emissions. The report highlights the critical importance of limiting global temperature rise to 1.5 degrees Celsius above pre-industrial levels in order to address climate uncertainty and mitigate the impacts of extreme weather events (IPCC, 2022). While the report acknowledges that current climate pledges are insufficient to achieve this goal, there are yet promising trends in the environmental data of the United States (U.S.), which has been one of the global leaders in emitting GHGs, particularly in the manufacturing sector.

Fig. 1(a) illustrates a consistent decline in pollution from the U.S. manufacturing sector over the past two decades. According to Shapiro and Walker (2018), the decline in pollution from U.S. manufacturing can be attributed to the implementation of intensified environmental regulations. These regulations have led to improvements in production efficiency, as measured by emission intensity, which represents the total emissions per unit of output. However, is escalating the stringency of environmental policies the sole avenue through which the U.S. can contribute to global efforts in addressing climate change?

Figs. 1(b) and 1(c) highlight that the improvement of U.S.' environmental quality has occurred alongside the expansion of international intermediate input trade via the global value chains (GVCs) and the overall currency depreciation of the U.S. dollars compared to major trade counterparts' currencies represented by the declining trend of real effective exchange rates (REER). This suggest that the U.S. has been able to balance economic growth with environmental concerns, leading to positive outcomes in terms of environmental quality.

To understand their relationships, we must consider the impact of central bank policies on domestic credit costs, the value of a country's currency relative to foreign currencies and their economic consequences. When the central bank tightens monetary policy, such as the Federal Reserve (Fed) raising nominal interest rates in the U.S., it leads to higher credit costs for businesses and attracts carry traders to invest in U.S. bonds (Anzuini et al., 2012). The increased demand for U.S. bonds causes the dollar to appreciate, impacting the international trade activities of U.S. firms engaged in GVCs. The strengthening of the dollar diminishes the competitiveness of U.S. intermediate exports, resulting in higher prices compared to foreign alternatives. As a consequence,

* Corresponding author.
*E-mail addresses:* goniyo@hanbat.ac.kr (K.-G. Kim), dpark@walton.uark.edu (D. Park).

https://doi.org/10.1016/j.jclepro.2023.138730
Received 10 April 2023; Received in revised form 14 August 2023; Accepted 6 September 2023
Available online 8 September 2023
0959-6526/

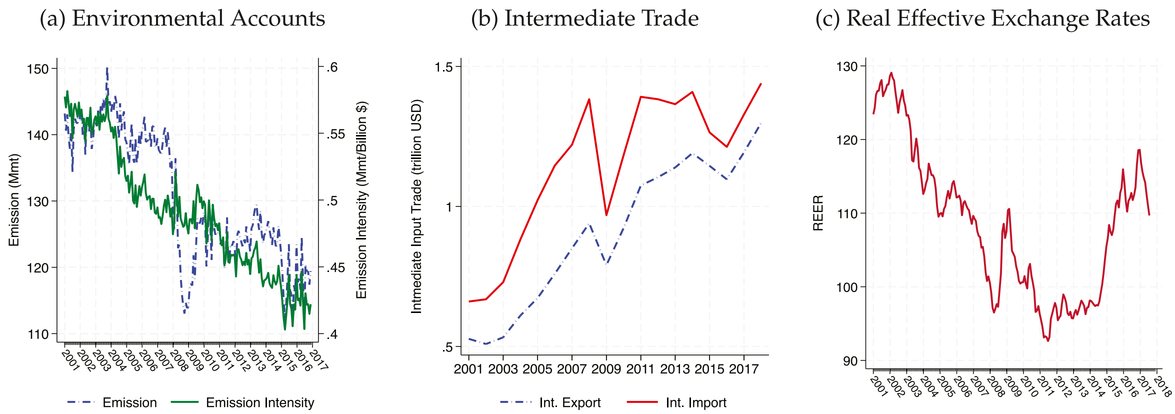


**Fig. 1.** Trends in the environmental quality, intermediate input trade and REER of the U.S.
*Notes:* These figures display the temporal patterns of carbon dioxide ($CO_2$) emissions and emission intensity, as well as the fluctuations in real effective exchange rates (REER) and intermediate input trade. The emissions are measured in million metric tons (Mmt), while emission intensity is expressed as Mmt of $CO_2$ per billion dollars (constant, 2010 $) with seasonality adjustments. Intermediate input trade is quantified in trillion U.S. dollars. The REER is a unit-less measure that reflects the relative value of the U.S. dollar compared to its trading partners, considering their trade weights.
*Source:* OECD-TiVA, Global Economic Monitor (World Bank) and Energy Information Administration (EIA).

the decline in exports has negative impacts on the level of intermediate imports and domestic production, which in turn entail environmental implications (Cole et al., 2017; Li and Zhou, 2017).

Despite the existence of such channels linking monetary policy to unintended environmental outcomes, there has been a surprising lack of attention to this aspect. In this study, therefore, our specific objectives are twofold: (a) to examine whether monetary policy influences environmental accounts through intermediate input trade, and (b) to quantify the magnitude of the causal relationship, if it exists. Our study specifically centers on the U.S. as a case study to gain deeper insights into these relationships, given its prominent role in both the foreign exchange and international trade markets.

### *1.2. Literature review*

This research is situated within three main strands of literature: firstly, the environmental impact of international trade and its various channels; secondly, the effects of monetary policy on emission levels; and lastly, the influence of monetary policy on exchange rate variations.

#### *1.2.1. The channels international trade affect environmental quality*

Over the years, extensive academic research has established that freer international trade contributes to maintaining a greener environment through firm-sorting processes (Baldwin and Ravetti, 2014; Holladay and LaPlue III, 2021), reallocation of market share towards more productive firms (Kreickemeier and Richter, 2014) and/or encouraged abatement investments arising from foreign competitions (Forslid et al., 2018). As production fragmentation has become an important feature of international trade for the past few decades, intermediate input trade (i.e., outsourcing/offshoring production) through the GVCs has also been spotlighted as an additional determinant of domestic environmental quality (Cole et al., 2017; Li and Zhou, 2017).

#### *1.2.2. Monetary policy effect on emission levels*

Our study aligns with recent research on the environmental impact of monetary policy. For example, Chishti et al. (2021) and Qingquan et al. (2020) reveal that contractionary monetary policy is linked to lower carbon-equivalent emissions in BRICS and selected Asian economies. In contrast, Liguo et al. (2022) finds that an expansionary monetary policy is associated with increased emissions. Similar in spirit to our research, Attílio et al. (2023) consider bilateral trade as a proxy for GVCs and find that tightening monetary policy leads to lower carbon emission level.

#### *1.2.3. Monetary policy and exchange rate variations*

A considerable body of research has examined the cross-border spillover of U.S. monetary policy on exchange rates. It is well-established that a contractionary U.S. monetary policy is linked to a sustained appreciation in the U.S. real exchange rates (Eichenbaum and Evans, 1995), and the exchange rate pass-through from monetary policies plays a critical role in determining international trade activities, as changes in the value of local currency alter import and export prices (Baldwin and Krugman, 1989; Iacoviello and Navarro, 2019).

Empirical studies, such as Bussière et al. (2020), have demonstrated the connection between changes in exchange rates and trade balances in 51 advanced and emerging-market economies. However, examining the global spillover of monetary policy on exchange rates requires consideration of GVC activities (Wei and Xie, 2020). The magnitude of spillovers of U.S. monetary policy, as shown by Georgiadis (2016), depends on the receiving country's trade integration. Moreover, Bruno et al. (2018) find that movements in exchange rates are closely linked to GVCs and credit conditions. Specifically, a weaker local currency against the dollar leads to tighter credit conditions and discourages GVC activity.

### *1.3. Contribution to the literature*

In light of the three areas of research, this study is distinctive in several manners:
**[1]** This paper expands on the current literature by examining the environmental consequences of the U.S.'s forward and backward linkages in GVCs. However, unlike previous studies, we investigate the dynamic nature of U.S. GVC activities in response to exchange rates and domestic credit costs influenced by monetary policy. This novel approach sheds light on the underexplored relationship between these factors and their impact on environmental quality, contributing to the growing understanding of the complex interactions between GVC dynamics, central bank's macroeconomic policy, and the environment.
**[2]** Our study complements past studies examining the unintended environmental outcomes of monetary policy and consistently finding that contractionary policy reduces carbon emissions. However, our study is distinct in three ways. First, we develop an economic model that illustrates how multinational firms optimize production fragmentation, which affects both emissions and economic value. We show that higher domestic credit costs discourage offshoring and lead to increased emission per unit of output despite lower emission levels. Second, we use the Fed Funds futures rate as an external instrument in a proxy-vector autoregression (VAR) method to mitigate endogeneity problems

associated with interest rates. Lastly, we focus on emission intensity, which incorporates both emission levels and production efficiency related to intermediate input sourcing via GVCs. These three features are largely absent in the past studies.

**[3]** The environmental impact of exchange rates and domestic credit costs variation has not been extensively explored in the literature. To address this gap, we investigate the environmental externality resulting from monetary policy, particularly through changes in exchange rates, domestic credit costs and international trade activities via input–output linkages.

### 1.4. Research design, findings and implications

#### 1.4.1. Method

To answer the research questions, we develop a partial equilibrium economic model and employ a proxy-VAR method. This approach allows us to elucidate the economic mechanisms through which monetary policy impacts a nation's environmental accounts and quantify the magnitude of this effect while mitigating potential econometric issues arising from bias-inducing endogeneity problems. Furthermore, our study goes beyond traditional measures of environmental outcomes, which typically focus on emission levels alone (Qingquan et al., 2020; Attílio et al., 2023). Instead, we specifically investigate emission intensity, which takes into account not only the absolute emissions but also the efficiency of production, particularly in relation to foreign input sourcing. This allows for a more comprehensive understanding of the environmental consequences of monetary policy and intermediate input trade.

In our economic model, we specifically introduce a representative multinational enterprise (MNE) that serves as a key player in determining the level of offshoring activities in response to changes in domestic credit costs, which are influenced by monetary policies. The degree of offshoring undertaken by the MNE reflects the extent of a country's participation in GVCs, which in turn affects both the production of outputs and emissions through intermediate input trade. Our analysis reveals that an increase in credit costs results in lower emissions overall, as the discouraged offshoring activities of the MNE lead to reduced production. However, it also leads to higher emission intensities, as the loss of production efficiency associated with decreased offshoring offsets the direct decrease in emissions. In other words, although emissions decrease in absolute terms, emissions per unit of output increases due to the decline in productivity-enhancing offshoring activities.

Empirically quantifying the causal relationships between monetary policy, intermediate input trade, and environmental outcomes poses significant challenges. This is primarily due to the potential endogeneity problem associated with monetary policy, as it is often influenced by past and concurrent economic conditions that may also have environmental consequences. Hence, simply including interest rates as a direct variable in the analysis can lead to biased causal estimates. To overcome this concern, we employ a proxy-VAR method and use U.S. monetary policy surprises as an external instrument, which has been relatively underexplored in previous studies. By capturing exogenous variation in the shock of interest, an instrument helps estimate dynamic causal effects of macroeconomic shocks (Stock and Watson, 2018). We use the term "monetary policy surprise" to refer to the changes in the Fed Funds futures rate observed 10 min before and 20 min after the Federal Open Market Committee (FOMC) announcement. This 30 min interval captures the unanticipated component of the Fed's decision regarding the Fed Funds rate target. We employ the monetary policy surprise as an external instrument for REER because we believe that the monetary policy surprise primarily affects emissions through its influence on variations in REER, which in turn impact production and trade activities. By identifying the impulse responses of the emissions and emission intensity to a monetary policy shock via intermediate exports, imports and industrial production, we demonstrate the impact of credit costs on the environmental accounts of the U.S.

#### 1.4.2. Findings

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, more importantly, 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 exports of domestic contents embodied in foreign exports and the imports of foreign value-added contents 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 U.S. dollars. Domestic industrial production activities dwindle and total generation of pollutants diminishes accordingly. However, notably that emission intensity – which is the main focus on this paper – rises 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.

#### 1.4.3. Implications

As we face increasing challenges related to climate change and environmental degradation, these findings suggest that it is imperative that policymakers recognize the externality of monetary policies in shaping environmental outcomes. We emphasize the importance of considering potential environmental outcomes when formulating and implementing monetary policies, aligning with the growing societal demand for sustainable economies. By highlighting the unintended environmental consequences of monetary policy, we suggest policymakers to view these policies as complementary to environmental regulations, recognizing their crucial role in addressing environmental challenges and fostering sustainable and resilient economies.

The rest of paper is structured as follows: Section 2 presents the theoretical mechanism explaining the impact of monetary policy on a country's environmental accounts. In Section 3, we outline the empirical identification strategy, followed by the presentation of the results in Section 4. Section 5 discusses the strengths, limitations, and policy implications of our study, while Section 6 provides a concluding summary.

## 2. 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 the level of emission and emission intensity (i.e., emission level per unit of output) vary by domestic credit condition, and then empirically study how the environmental accounts alter by the variation of (real effective) exchange rates.[1]

### 2.1. 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

[1] Through out the paper, we use terms environmental accounts and (domestic) environmental quality interchangeably although carbon dioxide, which is a global pollutant, is used for the empirical analyses because both global and local pollutants are, in general, emitted during the process on manufacturing.

**Table 1**
Cash flows of a firm in the supply chain.

| | | Production stages | | | | | Cumulative cash flow |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | ⋯ | $n-1$ | $n$ | |
| Date $t$ | 1 | $-\omega$ | | | | | $-\omega$ |
| | 2 | $-\omega$ | $-\omega$ | | | | $-3\omega$ |
| | ⋮ | | | ⋱ | | | ⋮ |
| | $n$ | $-\omega$ | $-\omega$ | ⋯ | $-\omega$ | $-\omega$ | $-\frac{n(n+1)}{2}\omega$ |
| | $n+1$ | $y(n)-\omega$ | $-\omega$ | ⋯ | $-\omega$ | $-\omega$ | |
| | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | |

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: 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 $L/n$ plants in each stage, the aggregate financing requirement in the economy, $K$, thus can be denoted as

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

Eq. (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.

### 2.2. Production fragmentation and the environment

#### 2.2.1. 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 $i$th 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.[2] 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

$$K = \frac{\bar{n} + s + 1}{2} \omega L, \tag{6}$$

where $L$ is the total endowment of labor force. In conjunction with the interest rate $r$, which determines domestic credit costs, Eqs. (5) and (6) will be used to derive the optimal number of production stages offshored abroad in the later section.

#### 2.2.2. 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:

$$E = \sum_{i=1}^{\bar{n}} e_i \tag{7}$$

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.

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

$$\begin{aligned} E(\bar{n}; s) &= \bar{n} - s + \left( d^{FP} + d^{BP} \right) s, \\ &= \bar{n} + \left( d^{FP} + d^{BP} - 1 \right) s \end{aligned} \tag{8}$$

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.[3]

The above equation implies that the comparative static illustrating the marginal effect of offshoring production stages on pollution emissions (i.e. $\frac{\partial E}{\partial s}$) is ambiguous because the net environmental damage from backward and forward GVC participation depends on the characteristics of dominant industries and tasks on which a country specializes (i.e., the position of a country in the GVCs): $d^{FP} + d^{BP} - 1 \lessgtr 0$. Despite

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

[3] 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.

such ambiguity, we conceive the net effect is likely to be positive since, while pollution offshoring via backward participation strictly reduces total stock of ambient air pollution, production fragmentation (i.e., FP and BP) brings a strong momentum in lowering air quality via encouraged production activities from specialization on tasks with absolute/comparative advantage (i.e., the scale effect).[4] Thus, we assume that the marginal effect of forward participation in generating emissions dominates that arising from backward participation: $d^{FP} + d^{BP} - 1 > 0$. It implies that the greater extent of production fragmentation the greater amount of pollution emissions are generated[5]:

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

### 2.2.3. 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 following profit maximization problem and zero-profit condition in conjunction with Eq. (6):

$$\max_{s} \ \Pi = (\bar{n} + bs)^{\alpha} L - \omega L - rK \quad \text{and} \quad \Pi = 0,$$

which yield

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

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

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

*Emission.* 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 production fragmentation: the participation of a country to the global value chain is discouraged.*

*Emission intensity.* The second environmental account we consider is emission intensities, which is defined as total emission per unit of total output:

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

where $Y(\bar{n};s)$ is the total sales from output production in the supply chain.[6] 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:

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

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 large enough to ensure an interior solution – 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 and Fig. 2 visually illustrates the cases:

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

Fig. 2 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.

We can intuitively understand these dynamics as follows. The MNE offshores intermediate tasks in order to improve total revenue by maximizing production efficiencies. The improvement of efficiencies are realized by two margins. First, the amount of traded intermediate inputs is maximized since the offshored tasks are conducted from where the full production efficiency is guaranteed: the intensive margin of trade. Second, the increase of trade partner varieties (i.e., the number of stages fragmented in our framework) improves sourcing opportunities, which in turn enables to further improve productivity: the extensive margin of trade. However, the gains from trade are not indefinite as the marginal returns of production fragmentation (or GVC participation from broader interpretation) is diminishing because offshoring entails

[4] Our empirical analyses focus on broadly defined manufacturing sector of the U.S. which includes energy-intensive sectors (e.g., Primary metals, Fabricated metal products, Machinery, Petroleum and coal products, Chemical products and Plastic and rubber products). According to the data from Bureau of Economic Analysis, these sectors took almost 80% of total manufacturing GDP in 2019. Due to their dominance in value-added, we do not conceive the assumption of positive net effect of GVC participation on total pollution generation is far-fetched especially at the level of national average.

[5] 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.

[6] 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 revenue regardless of the production origin.

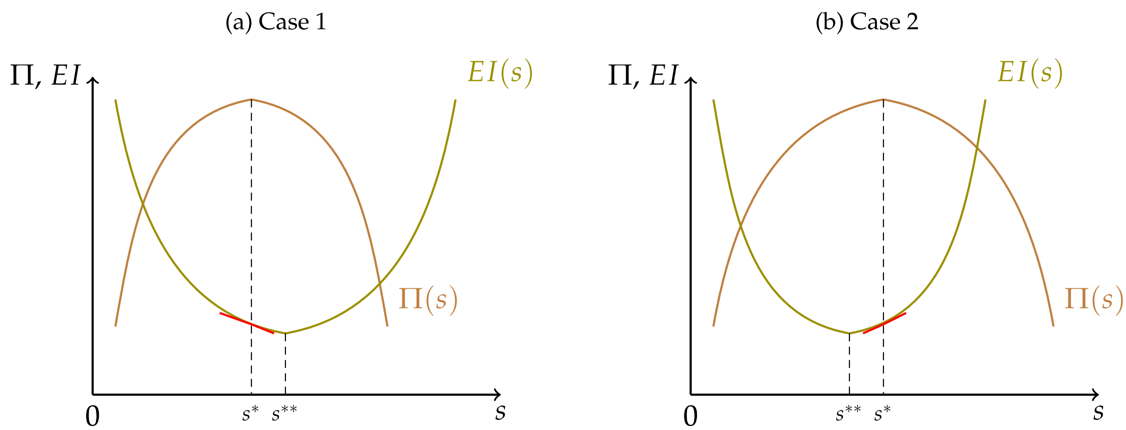


**Fig. 2.** Production fragmentation and emission intensity.
*Notes:* This figure describes the marginal effect (the red line) of offshoring on emission intensity under two scenarios. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

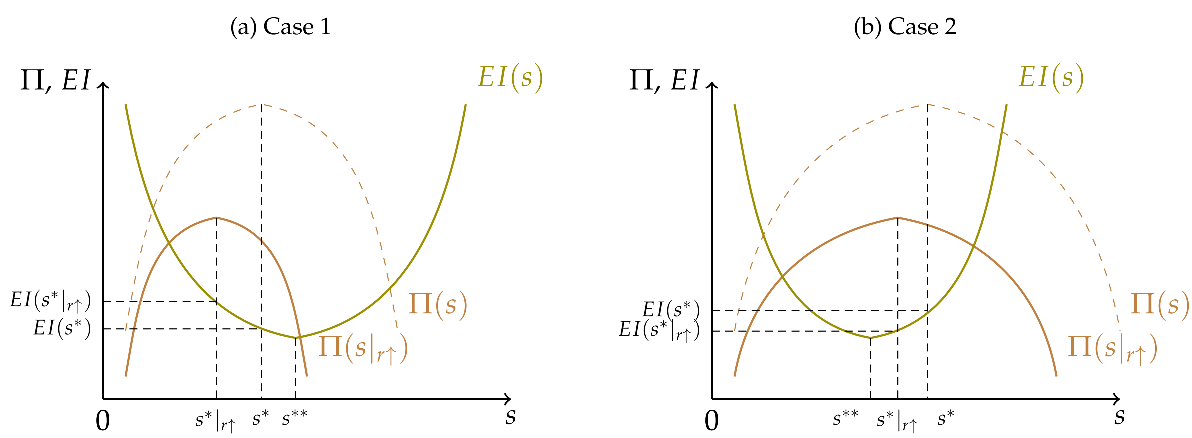


**Fig. 3.** Differential effect of credit costs on emission intensity.
*Notes:* This figure describes the effect of domestic credit costs on the variation of emission intensities under two scenarios.

prolonged shipping time reflected by increased working capital in the model. Although not directly modeled, the extended transportation time may implicitly include searching costs of potential trade partners (i.e., offshoring destination). Thus, whether to implement policy instruments to encourage firms to increase the extent of production fragmentation needs to be considered from the comparison of socially and privately optimal levels of offshoring.

*Credit cost and emission intensity.* 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.*

Fig. 3 presents these two cases. 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 at the cost of discouraged economic activities because of high credit costs.

The effect on emission intensity is theoretically more nuanced. In Case 1, we present a scenario where the positive effect of offshoring on total value generated outweighs its impact on emissions. This suggests that the socially optimal level of production fragmentation is likely higher than the level determined solely by private optimization. Consequently, when a contractionary monetary policy increases domestic credit costs, it can result in higher emission intensities. This occurs because the policy discourages firms from engaging in offshoring activities, causing the equilibrium number of offshored production stages to deviate further from the socially optimal level.

In Case 2, we examine a situation where the negative environmental consequences of offshoring outweigh the positive impact on total economic value. This implies that the socially optimal level of offshoring is likely to be lower than what would be determined by private optimization alone. Therefore, a contractionary monetary policy that discourages firms' offshoring activities may lead to lower emission intensities.

Given the theoretical ambiguity regarding the direction of emission intensity in response to the increase in domestic credit costs, the empirical investigation becomes crucial to establish a causal relationship between the value of the domestic currency and its environmental consequences. In the subsequent section, we outline the empirical identification strategy that supports the causal effect of domestic credit costs, influenced by monetary policy, on the environmental accounts we have identified theoretically.

## 3. Empirical identification

### 3.1. 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

$$By_t = C(L)y_t + \varepsilon_t, \tag{9}$$

where $y_t$ is an $n \times 1$ vector of endogenous variables,[7] $B$ and $C$ are matrices of the estimated coefficients,[8] and $L$ is a lag operator.[9] A $n\times 1$ vector of structural shocks denoted as $\varepsilon_t$ are defined as follows:

$$\varepsilon_t \sim i.i.d.\ N(0, \Omega), \quad \text{where} \quad \Omega = I_n. \tag{10}$$

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

$$\frac{\partial y_{t+h}}{\partial \varepsilon_t}, \quad h = 1, 2, 3\ldots \tag{11}$$

In order to identify the impulse response of $y_t$ with respect to $\varepsilon_t$, we need to transform Eq. (9) to a reduced form[10]:

$$y_t = A(L)y_t + \upsilon_t, \tag{12}$$

where $A(L) = B^{-1}C(L) = A_1 L + A_2 L^2 + \cdots + A_i L^i$, and $i$ is the number of lag. $\upsilon_t$ is the reduced form shock, given by

$$\upsilon_t = S\varepsilon_t, \tag{13}$$

with $S = B^{-1}$. The variance–covariance matrix, $\Sigma$, of an error term in Eq. (12) is

$$\Sigma = E[\upsilon_t \upsilon_t'] = E[SS']. \tag{14}$$

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

$$y_t = A(L)y_t + S\varepsilon_t. \tag{15}$$

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 $y_t$.[11] 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:

$$E[z_t \varepsilon_t^{p\prime}] = \Phi, \tag{16}$$

$$E[z_t \varepsilon_t^{q\prime}] = 0, \tag{17}$$

where $\varepsilon_t^p$ is the $k \times 1$ shock of interest vector and $\varepsilon_t^q$ denotes all other $(n-k) \times 1$ vector of shocks. The relevance condition in Eq. (16) means that the instrument should be correlated with the endogenous shock variable of our interest, $\varepsilon_t^p$. The exogeneity condition in Eq. (17) implies that the instrument affects the dependent variable only via $\varepsilon_t^p$ and is orthogonal to other shock variables, $\varepsilon_t^q$. With $z_t$ which satisfies these conditions, the two-stage least squares (2SLS) allows for the estimates of $S$ (Gertler and Karadi, 2015).[12] Then, with the estimates of $S$, we can identify the dynamic causal effect of the structural shocks ($\varepsilon_t$) on $y_t$.

### 3.2. Data

We use monthly-level data of real effective exchange rates (REER), import, export, industrial production, $CO_2$ emission intensity of the U.S. from August 2001 to August 2017 as the endogenous variables ($y_t$).[13] 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 emission intensities. In order to consider forward and backward linkages of the U.S. in GVCs, we also derive monthly exports of domestic contents embodied in foreign countries' exports, and imports of foreign value-added contents from August 2001 to July 2017 from OECD-TiVA database.[14]

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 of real effective exchange rates. To this end, the monetary policy surprise satisfies both relevance and exogenous conditions described in Eqs. (16) and (17).

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

$$FF_t = (Expected_{t,+20} - Expected_{t,-10}). \tag{18}$$

To calculate $Expected_{t,-10}$ and $Expected_{t,+20}$, we exploit changes in the Fed Funds Futures rate between 10 min before and 20 min after the

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

[8] 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.

[9] In a time series analysis, a lag operator is used for a convenient representation of lag variables. For example, $C(L) = C_1 L + C_2 L + \cdots + C_p L$ for VAR($p$). Then, $C(L)y_t = C_1 y_{t-1} + C_2 y_{t-2} + \cdots + C_p y_{t-p}$.

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

[11] 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.

[12] The intuition is as follows: First, the reduced form VAR in Eq. (12) provides estimates of $\upsilon_t$. Let $\upsilon_t^p$ be the residual which corresponds to $\varepsilon_t^p$ in Eq. (13). Likewise, let $\upsilon_t^q$ be the residual which connects to $\varepsilon_t^q$. Next, the regression of $z_t$ on $\upsilon_t^p$ yields $\widehat{\upsilon_t^p}$. Then, the regression of $\upsilon_t^p$ on $\widehat{\upsilon_t^p}$ allows for estimating the elements in $S$ that are related to the structural shock $\varepsilon_t^p$.

[13] 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.

[14] 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.

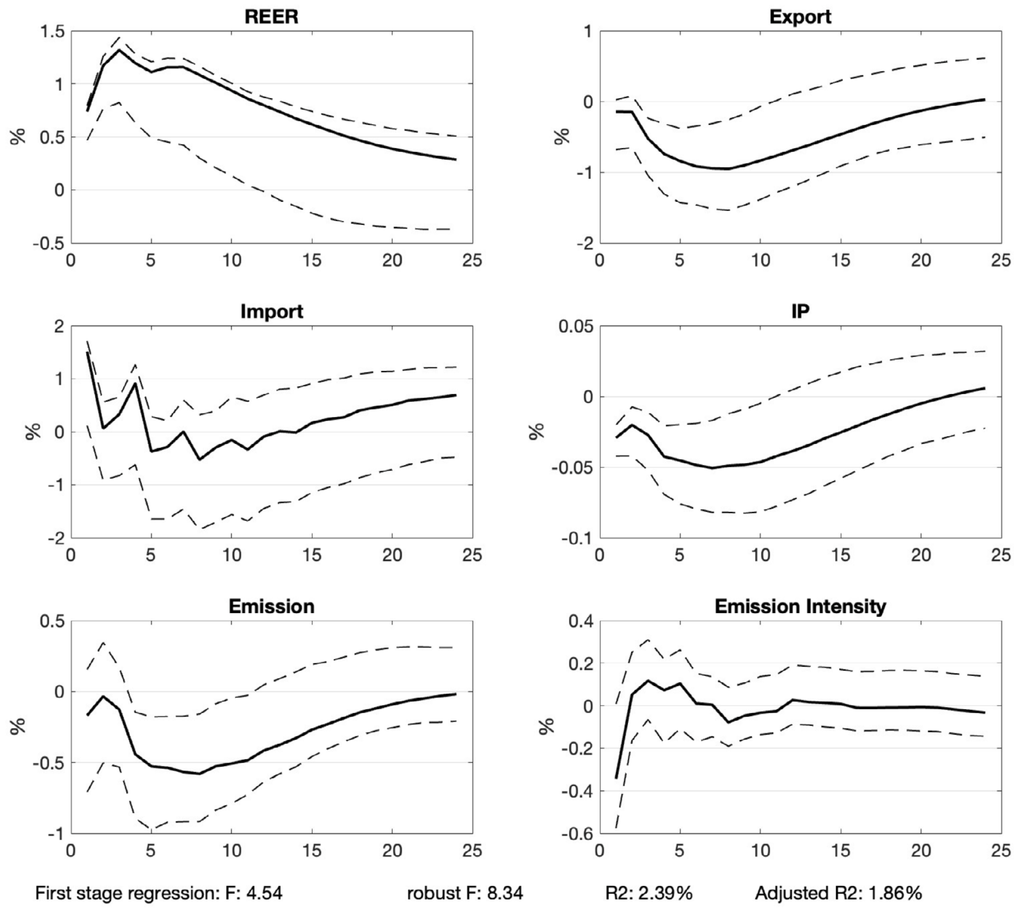


**Fig. 4.** The effect of monetary policy shock on environmental accounts.
*Notes:* We use monetary policy surprises as an external instrument to estimate impulse responses. The dotted line represents 90 percent confidence interval, calculated by bootstrapping methods. We report a robust F-value to address a possible heteroskedasticity.

FOMC decision. Within a 30 min 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.[15] 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.

## 4. Results

In this section, we empirically demonstrate the impact of credit costs and real effective exchange rates on the environmental accounts by implementing the proxy-VAR method using monetary policy surprises as an external instrument.

### *4.1. Gross imports/exports and the environment*

As shown in Fig. 4, a surprising monetary tightening by a one standard deviation leads to an increase in real effective exchange rate, which is statistically 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. However, with a monetary policy surprises as an instrument, a robust $F$-value of 8.34 indicates a weak instrument problem when the features of GVCs are not incorporated.

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. However, the magnitude that the imports alter is statistically very weak. Domestic industrial production also drops accordingly. Overall, the responses confirm the conventional view about a relationship between REER and real variables.

Then, 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. 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. It is noticeable that total $CO_2$ emissions drop while emission intensities are not affected by monetary tightening which is not consistent with the findings of the model introduced earlier. We thus narrow down our focus on addressing intermediate input trade and its environmental consequences in the following section.

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

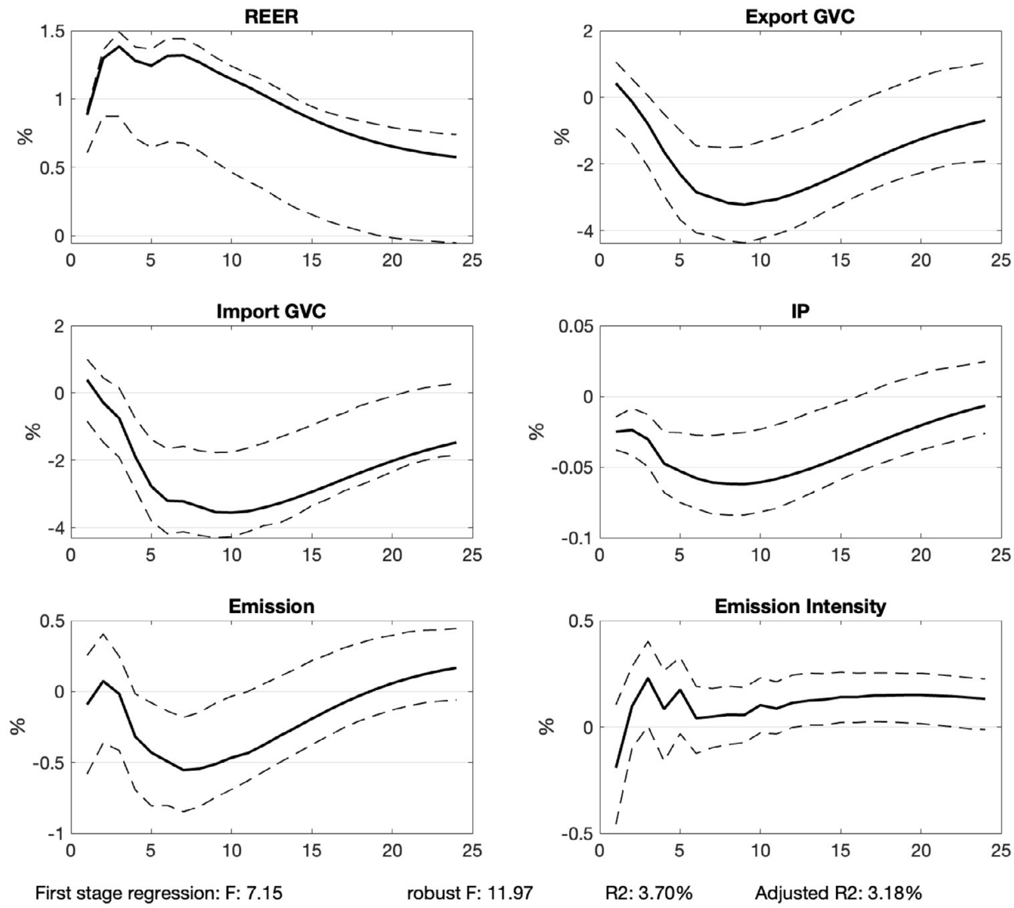


**Fig. 5.** The effect of monetary policy shock on environmental accounts via GVC.
*Notes:* We use monetary policy surprises as an external instrument to estimate impulse responses. The dotted line represents 90 percent confidence interval, calculated by bootstrapping methods. We report a robust F-value to address a possible heteroskedasticity.

### *4.2. 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.

Fig. 5 shows how the macroeconomic impulse propagates through the channel of global value chains and ultimately affects environmental accounts in the U.S.[16] In response to a surprising monetary tightening inducing stronger dollar, the exports of domestic contents embodied in the foreign countries' exports diminish (this is referred as "Export GVC" in the figure) within approximately five to fifteen-month periods.[17] 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 (denoted as "Import GVC" in the figure) shrinks contemporaneously with loosened forward linkage of the U.S. This suggests that importing activities are strongly tied with exporting decisions of firms particularly in the global production networks.[18] These facts are consistent with a theoretical finding that the greater domestic credit costs and stronger local currency are associated with the reduction in offshoring activities, which in turn implies that the number of foreign trade counterparts (or subsidiaries of the firm) diminishes as a consequence of surprising monetary policy—the extensive margin of trade.

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 to those of forward and backward participation to the value chains. In other words, a contractionary monetary policy which induces 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.[19]

The response of emission intensity to monetary policy surprises differs from the response of emissions themselves. While the changes in

[16] In contrast to the previous results, the robust $F$-value is now 11.97 implying that the instrument we use is statistically significant when intermediate input trade is taken into account.

[17] The weakened forward linkage recovers as the shock of monetary surprising dwindles over time.

[18] 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.

[19] This finding is consistent with that of Attílio et al. (2023) in that the positive environmental outcome arises approximately within 15 months; however, we find a much stronger effect of monetary tightening perhaps because we have addressed a potential omitted variable bias by using an external instrument which may arise when domestic interest rates are directly used in the estimation.

emissions may be observed relatively quickly after a monetary policy shock, the impact on emission intensity takes more time to materialize. Specifically, it is found that the effect on emission intensity becomes statistically significant approximately ten months after the surprise.

This result is expected and aligns with our understanding of the complexities involved in firms' decisions related to offshoring or outsourcing of intermediate inputs. These decisions are influenced by factors such as search frictions and lock-in effects, which can prolong the initiation or termination of production linkages (Antràs and Chor, 2022). As a consequence, when a contractionary monetary policy shock occurs, there is a time lag during which the number of input varieties decreases.

The time lag in response to a contractionary monetary policy shock triggers changes in the composition of inputs, which can have implications for emission intensity. As the shift in the input portfolio favors domestic varieties, it is possible that these domestic inputs have higher carbon emissions compared to the foreign input varieties that are being reduced. This change in input composition directly affects the efficiency of industrial production, leading to worsened emission intensity.[20]

The first case in Fig. 3 is consistent with the empirical findings. From the conceptual framework described earlier, we can infer that the U.S. 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 measured in emission intensity can be improved by international intermediate input trade when it is combined with macroeconomic policies.[21]

In essence, the empirical analysis results unequivocally establish the notable causal connections linking monetary policy with environmental accounts. While prior research has predominantly centered on the economic ramifications of monetary policy, our study introduces a new dimension by investigating its impact on environmental quality, not only measured by emission level but particularly by emission intensity.

Our findings highlight the far-reaching influence of central bank monetary policy. Not only does it shape exchange rates (alongside domestic credit costs) and trade patterns, but it also significantly impacts emissions, with a special emphasis on emission intensity within GVCs. More specifically, our study uncovers that a hike in the Fed's interest rate curtails trade activities via a rise in REER. This is translated into a reduction in emissions as a result of discouraged economic activities, while concurrently intensifying the emission intensity.

This nuanced outcome underscores that higher benchmark interest rates, leading to supply chain restrictions, diminish the outsourcing of production activities tied to emissions. As a result, this leads to reduced production efficiencies. Importantly, our study underscores that monetary policy exercises a considerable, albeit indirect, influence on environmental outcomes, parallel to its impact on economic variables like inflation and exchange rates. In the following section, we provide a detailed policy implication of our findings.

[20] It is important to note that the effect of a contractionary monetary policy on emission intensity may vary by countries depending on the their input portfolio. For instance, if a country predominantly sources pollution-causing inputs from abroad, the shift towards relatively less pollution-inducing domestic inputs would improve emission intensity, which is contrary to the findings observed for the U.S. in this study.

[21] 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.

## 5. Discussion

In this section, we highlight the robustness and reliability of our chosen identification strategy in addressing the research question. Additionally, we acknowledge and discuss relevant caveats that should be taken into account to ensure a comprehensive understanding of the paper. We further expand this section by examining the policy implications derived from our findings, emphasizing the significance of considering unintended externalities when designing monetary policy.

### 5.1. Robustness and caveats

One of the major challenges in estimating the environmental impact of monetary policy is disentangling the pure causal effect of the central bank's policy instrument from other economic factors that may be correlated with both the policy of interest and environmental outcomes. Neglecting this endogeneity problem and simply regressing time-varying emissions and emission intensities on interest rates can lead to biased causal estimates and inaccurate statistical inference. To overcome this challenge, we employ a proxy-VAR methodology, which has not been extensively explored in previous literature, and specifically use changes in the Fed Funds Futures rate within a narrow 30 min window around the FOMC decision as an external instrument.

By focusing on this precise time window, we minimize the potential influence of simultaneous events and ensure the exogeneity of the policy shock. We impose restrictions that capture the impact of monetary policy surprises on environmental variables solely through variations in real effective exchange rates, which govern international trade and domestic production activities. This satisfies both the relevance and exogeneity conditions and allows us to properly identify the dynamic causal effect of monetary policy on environmental variables.

The distinctive aspect of our paper lies in our methodology, which carefully addresses the bias-inducing endogeneity problem. This sets our study apart from previous research that has explored similar questions.

One of the principal findings of our research is that a contractionary monetary policy leads to a decline in emission levels, primarily driven by reduced intermediate trade via GVCs and production activities. This discovery is in line with previous literature (e.g., Qingquan et al., 2020; Chishti et al., 2021; Attílio et al., 2023) that employed diverse identification methods. Unlike previous studies that have predominantly concentrated on quantifying the changes of global pollutant levels, our research expands on these findings by centering on "emission intensity". This approach uncovers that efforts by central banks to bolster domestic currency are linked to *heightened* emission levels per unit of output. This novel outcome suggests a decrease in production efficiency due to limited opportunities for input sourcing from abroad through GVCs. Interestingly, this aspect has been under-explored in prior studies that raised similar inquiries.

There are several important caveats that should be considered to better understand our paper. Firstly, while we have access to high-frequency financial data such as real effective exchange rates and Fed funds rates, the data on international trade associated with global value chains (GVCs) is only available at an annual level. Therefore, we make the assumption that the monthly backward and forward linkages of the U.S. remain constant within a year. However, to more accurately account for the environmental externality of macroeconomic shocks through GVCs, it is necessary to conduct more detailed analyses using alternative trade and GVC-related variables that can be better tied with high-frequency changes in the financial sector.

Another important point to note is the asymmetric effects of monetary policy. According to the metaphor that monetary policy and the economy are tied to both ends of the string, a string-pulling monetary tightening would work well, while a string-pushing monetary easing would not work as well (Barnichon et al., 2017). For example, Tenreyro and Thwaites (2016) provide empirical evidences that contractionary monetary shocks are more powerful than expansionary shocks. This implies that the extent of environmental impacts of monetary policy may also be asymmetric. Our VAR model is limited to analyze the state-dependent impact of monetary policy on environmental variables in an expansion or recession. Thus, further research is needed to investigate how much the asymmetric response of environmental variables to a monetary policy depends on the state of the business cycle.

### 5.2. Policy implications

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.[22] 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.[23]

On the other hand, 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.[24] Furthermore, we can envision that 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 not only to achieve it primary goal but to function as an indirect instrument of addressing environmental concerns.

[22] 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.

[23] 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.

[24] There are many papers focusing on firms' behavior of outsourcing pollution abroad due to stringent domestic environmental regulations: so called Pollution Haven Hypothesis. See Cherniwchan et al. (2016) for detailed summary.

## 6. Conclusion

The increasing prominence of Environmental, Social, and Governance (ESG) practices highlights the growing societal demand for responsible business conduct, particularly in light of the environmental impact of production activities in an increasingly warming world. In today's highly interconnected global economy, industrial production is closely tied to international trade along GVCs, which in turn is influenced by monetary policies via domestic credit costs and exchange rate variations. The potential environmental impacts of the monetary policies, unfortunately, have often been overlooked, as policymakers traditionally prioritize ensuring economic stability.

This paper aims to examine and quantify the causal relationship between monetary policies and their environmental impacts, specifically focusing on the role of GVCs. We employ a novel methodological approach and expand the scope of analysis by considering not only emission levels but also emission intensity which differentiate our approach from those in the past studies. Specifically, we develop an economic model that illustrates the underlying mechanism. Building upon the model, we employ a proxy-VAR analysis using variations in the Fed Funds Futures rate within a 30 min window around the FOMC announcement that helps address the endogeneity problem and ensures accurate statistical inference. In addition to traditional measures of environmental outcomes, we expand our analysis to include emission intensity, which takes into account production efficiency alongside emission levels. Our results demonstrate that the reduced input sourcing from abroad, resulting from contractionary monetary policy, leads to lower production efficiency and increased emission intensity, which is an insightful finding largely absent in the past literature.

Our research findings are especially relevant and timely given the recent actions of the Federal Reserve (Fed) in raising the Fed Funds rate. The ongoing increase in the rate, currently at a range of 5.00–5.25 percent as of June 2023, aligns with the contractionary monetary policy scenario that we examined in our study. Our research highlights the potential for these recent actions by the Fed to have unintended and under-recognized environmental consequences. By shedding light on the environmental effects of such monetary policy decisions, our study emphasizes the importance of considering environmental impacts when formulating and implementing monetary policies especially given rapidly escalating needs for sustainable economies.

In addition, the environmental externality arising from monetary policies suggests that policymakers have the opportunity to view these policies as a complement to environmental regulations, beyond their primary role as economic stabilizers. Our findings provide valuable insights for policymakers seeking to create resilient economies in the context of the ESG era. By considering the environmental impact of monetary policy, policymakers can better integrate environmental considerations into their decision-making processes to contribute to clean and sustainable economies.

## CRediT authorship contribution statement

**Kyoung-Gon Kim:** Empirical analysis, Visualization, Writing – original draft, Review & editing. **Doyoung Park:** Conceptualization, Modeling, Visualization, Writing – original draft, Review & editing.

## Declaration of competing interest

We, Kyoung-Gon Kim and Doyoung Park, declare that we have no relevant or material financial interests related to the research described in this paper.

## Data availability

Data will be made available on request.

## References

Antràs, Pol, Chor, Davin, 2022. Global value chains. In: Handbook of International Economics, Vol. 5. Elsevier, pp. 297–376.

Anzuini, Alessio, Lombardi, Marco J., Pagano, Patrizio, 2012. The impact of monetary policy shocks on commodity prices.

Attílio, Luccas Assis, Faria, João Ricardo, Rodrigues, Mauro, 2023. Does monetary policy impact CO2 emissions? A GVAR analysis. Energy Econ. 119, 106559.

Baldwin, Richard, Krugman, Paul, 1989. Persistent trade effects of large exchange rate shocks. Q. J. Econ. 104 (4), 635–654.

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

Barnichon, Regis, Matthes, Christian, Sablik, Timothy, et al., 2017. Are the effects of monetary policy asymmetric? Richmond Fed Econ. Brief (March).

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

Bombardini, Matilde, Li, Bingjing, 2020. Trade, pollution and mortality in China. J. Int. Econ. 103321.

Bruno, Valentina, Kim, Se-Jik, Shin, Hyun, 2018. Exchange rates and the working capital channel of trade fluctuations. In: AEA Papers and Proceedings, Vol. 108. pp. 531–536.

Bussière, Matthieu, Gaulier, Guillaume, Steingress, Walter, 2020. Global trade flows: Revisiting the exchange rate elasticities. Open Econ. Rev. 1–54.

Cherniwchan, Jevan, Copeland, Brian R., Taylor, M. Scott, 2016. Trade and the environment: New methods, measurements, and results. Annu. Rev. Econ.

Chishti, Muhammad Zubair, Ahmad, Manzoor, Rehman, Abdul, Khan, Muhammad Kamran, 2021. Mitigations pathways towards sustainable development: Assessing the influence of fiscal and monetary policies on carbon emissions in brics economies. J. Clean. Prod. 292, 126035.

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

Eichenbaum, Martin, Evans, Charles L., 1995. Some empirical evidence on the effects of shocks to monetary policy on exchange rates. Q. J. Econ. 110 (4), 975–1009.

Forslid, Rikard, Okubo, Toshihiro, Ulltveit-Moe, Karen Helene, 2018. Why are firms that export cleaner? International trade, abatement and environmental emissions. J. Environ. Econ. Manag. 91, 166–183.

Georgiadis, Georgios, 2016. Determinants of global spillovers from US monetary policy. J. Int. Money Finance 67, 41–61.

Gertler, Mark, Karadi, Peter, 2015. Monetary policy surprises, credit costs, and economic activity. Am. Econ. J.: Macroecon. 7 (1), 44–76.

Holladay, J. Scott, LaPlue III, Lawrence D., 2021. Decomposing changes in establishment-level emissions with entry and exit. Canadian J. Econ. 54 (3), 1046–1071.

Iacoviello, Matteo, Navarro, Gaston, 2019. Foreign effects of higher US interest rates. J. Int. Money Finance 95, 232–250.

IPCC, 2022. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Cambridge University Press, Cambridge, UK and New York, NY, USA, p. 3056,

Kreickemeier, Udo, Richter, Philipp M., 2014. Trade and the environment: The role of firm heterogeneity. Rev. Int. Econ. 22 (2), 209–225.

Kuttner, Kenneth N., 2001. Monetary policy surprises and interest rates: Evidence from the fed funds futures market. J. Monetary Econ. 47 (3), 523–544.

Li, Xiaoyang, Zhou, Yue M., 2017. Offshoring pollution while offshoring production? Strateg. Manag. J. 38 (11), 2310–2329.

Liguo, Xin, Ahmad, Manzoor, Khattak, Shoukat Iqbal, 2022. Impact of innovation in marine energy generation, distribution, or transmission-related technologies on carbon dioxide emissions in the united states. Renew. Sustain. Energy Rev. 159, 112225.

Mertens, Karel, Ravn, Morten O., 2013. The dynamic effects of personal and corporate income tax changes in the United States. Amer. Econ. Rev. 103 (4), 1212–1247.

Qingquan, Jiang, Khattak, Shoukat Iqbal, Ahmad, Manzoor, Ping, Lin, 2020. A new approach to environmental sustainability: Assessing the impact of monetary policy on CO2 emissions in Asian economies. Sustain. Dev. 28 (5), 1331–1346.

Shapiro, Joseph S., Walker, Reed, 2018. Why is pollution from US manufacturing declining? The roles of environmental regulation, productivity, and trade. Amer. Econ. Rev. 108 (12), 3814–3854.

Stock, James H., Watson, Mark W., 2018. Identification and estimation of dynamic causal effects in macroeconomics using external instruments. Econ. J. 128 (610), 917–948.

Tenreyro, Silvana, Thwaites, Gregory, 2016. Pushing on a string: US monetary policy is less powerful in recessions. Am. Econ. J.: Macroecon. 8 (4), 43–74.

Wei, Shang-Jin, Xie, Yinxi, 2020. Monetary policy in an era of global supply chains. J. Int. Econ. 103299.