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### Conference Paper On the Drivers of Clean Production: Firms' Global Value Chain Positioning

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# On the Drivers of Clean Production: Firms' Global Value Chain Positioning

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#### Abstract

Industries that occupy upstream positions in global value chains (GVCs) - being positioned closer to the raw product - produce proportionately more  $CO_2$ -intensive. However, firms are heterogeneous, even in narrowly defined industries. In this paper, I empirically investigate whether the relationship between upstreamness and  $CO_2$  emissions, measured in absolute and relative terms, holds within industries at the firm level. Using granular data of Indian manufacturing firms and controlling for established drivers of clean production, I reveal that firms producing products closer to final consumption produce less  $CO_2$ -intensive. I corroborate the finding by using a 2-SLS instrumental variable approach. Interestingly, I find that exposure to importing countries with stringent environmental policies attenuates the link between upstreamness and dirty production. The latter finding suggests the imperative of technology upgrading for dirty upstream producers aiming to remain competitive in international markets.

JEL Classification Numbers: F14, F18, O13, Q56.

*Keywords:* Environment and trade; environment and development;  $CO_2$  intensity; global value chains; sustainable development.

### Highlights

- In this paper, I empirically investigate the relation between firms' CO<sub>2</sub> emissions and GVC positions
- I find that within industries firms that occupy upstream GVC positions produce more CO<sub>2</sub>-intensive
- Exposure to export markets with strong environmental regulation moderates (negatively) the relation between upstreamness and dirty production
- A firm's export status does not significantly moderate the relation between upstreamness and dirty production
- Accelerating the environmental abatement of firms in upstream GVC positions is key reaching global goals on CO<sub>2</sub> emissions

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### 1 Introduction

Promoting the green transition of industries is a pressing challenge of our time and it is covered in the United Nations Sustainable Development Goals 9 and 12. To date, economic growth has strongly correlated with energy consumption, which itself has strongly correlated with greenhouse gas (GHG) emissions (Costa-Campi, García-Quevedo, & Segarra, 2015). Global warming, a consequence of GHG emissions, represents a serious threat for future generations through increasingly volatile weather conditions, changed agricultural productivity, threatened biodiversity and elevated sea levels. Emerging and developing countries are especially vulnerable to the economic risks related to global warming. At the same time, with their economic rise, most of the global increase in GHG emissions originates from these countries (Copeland, Shapiro, & Taylor, 2021). Accordingly, beyond the urgency of a significant decoupling between economic growth and GHG emissions in industrialised countries, major successes in GHG emission reduction of developing and emerging countries are crucial if there is any hope of attaining the Paris Agreement's target of limiting global warming to well below 1.5°Celsius.

This paper, contributes to the understanding of the determinants of firms' clean production, measured as reductions of firms'  $CO_2$  emissions and  $CO_2$  intensity, in developing countries. In doing so, I complement prior studies on the relationship between a firm's global value chain (GVC) participation and its environmental performance - the focus being a firm's GVC positioning, rather than foreign ownership, export, or import status (Batrakova & Davies, 2012; Brucal, Javorcik, & Love, 2019; Gutiérrez & Teshima, 2018). To this end, I empirically analyse data of firms based in India, the third largest global emitter of  $CO_2$  and a country with historically high rates of emissions growth. A main contribution to the literature is whether Shapiro's (2021) finding of a negative relationship between industries' upstreamness and clean production can be confirmed at the firm level. Specifically, this means confirming whether firms located more upstream along the GVC - being positioned closer to the raw product than their peers producing a similar core product - demonstrate a worse environmental performance. Additionally, I investigate whether a firm's exports and exposure to export markets characterised by stringent environmental policies, negatively moderates the relationship for upstreamness.

The negative relationship between industries' upstreamness and clean production is monotonous and somewhat linear across industries and countries, at all stages of development (Shapiro, 2021). In line with this finding, Copeland et al. (2021) list as a stylised fact that upstream industries do indeed carry a heavier environmental footprint. However, firms are heterogeneous, even within narrowly defined industries (Melitz, 2003). Accordingly, relationships observed at the industry level cannot comment on firm level phenomena such as productivity, exports or product mix. These and other firm level idiosyncrasies, which potentially relate to the environmental performance of a firm, motivate this paper. There are strong intuitions why these firm level phenomena matter. Firstly, differences in the product mix are expected to connect both to a firm's GVC positioning as well as the environmental impact of its production. A manufacturing firm that also sells mining products is likely to report worse  $CO_2$  intensity than its peers because mining products require more energy, on average, during the production process. At the same time, mining products are more predominant in upstream GVC positions. Second, productivity varies substantially between firms within an industry and productive firms are more likely to participate in global trade (Melitz, 2003). A firm's trade participation can induce additional productivity gains, technology upgrading, and improvements in its environmental performance (Bustos, 2011; Cherniwchan, Copeland, & Taylor, 2017; Copeland et al., 2021; Shapiro & Walker, 2018).

Gutiérrez and Teshima (2018) argue that developing countries, in particular, can benefit environmentally from trade-induced technology adoption because firms based in these countries are, on average, further removed from the technology frontier. I argue that a similar claim might hold for the relationship between upstreamness and cleaner production. If firms in upstream value chain positions are characterised by a higher distance to the technology frontier, they might benefit disproportionately from trade-related drivers of cleaner production. These benefits from trade could be arise from learning-byexporting, demand-pull, and regulation-push (Brunnermeier & Cohen, 2003; De Loecker, 2007; Horbach, 2008). Additionally, they are more pronounced for firms exposed to countries with higher degrees of environmental policy stringency (EPS) (Hanley & Semrau, 2022). The latter might link to a negative moderating role of EPS exposure on the relationship between upstreamness and dirty production. However, strong environmental regulation in import destinations can cause firms in developing countries to fully specialise in the production of (dirty) inputs not conforming to these standards (Acemoglu, Aghion, & Hémous, 2014). Outsourcing of dirty production to countries with lax environmental regulation is in line with the pollution haven hypothesis, as outlined by Antweiler, Copeland, and Taylor (2001) and Eskeland and Harrison (2003).

Similar to Barrows and Ollivier's (2021) recent contribution on the nexus between the GVC participation of firms and their environmental performance, I use the Prowess database. I denote clean production by firms'  $CO_2$  emissions and  $CO_2$  emissions per unit of sales. Additionally, I follow Dardati and Saygili (2021), measuring firms'  $CO_2$  intensity by using  $CO_2$  emissions per unit of value added. In this way, value added is calculated by subtracting spending on intermediates from the sales of each firm, which covers the value of a good acquired in prior stages of the GVC. Producing these intermediates is linked to indirect emissions along the GVC, emissions that are emitted during the production of the intermediates and transportation. Accordingly, using  $CO_2$  per value added provides a measure for a firm's environmental performance at a specific stage of the value chain.

Exploiting firm level information, the  $CO_2$  emissions of a firm are calculated using data on the quantities of energy consumed, for each energy sources used. Such detailed firm level information is rare in the context of a developing country and makes it possible to regard differences in  $CO_2$  emissions between different sources of energy, in a way that is not captured if energy costs are applied as a proxy for clean production (Barrows & Ollivier, 2018, 2021). To measure the GVC position of a firm, I apply the industry level GVC measure of Antràs, Chor, Fally, and Hillberry (2012) and Antràs and Chor (2018). Specifically, I follow the methodology of Herkenhoff, Krautheim, Semrau, and Steglich (2021), calculating the Indian industry-year-specific GVC positions by employing the WIOD available for the period from 2000 to 2014 (Timmer, Dietzenbacher, Los, Stehrer, & Vries, 2015). I then combine the industry information with the product level information component of Prowess to calculate firm-specific GVC positions (Herkenhoff et al., 2021). Empirically, I apply an OLS regression, controlling for established drivers of clean production. By including industry fixed effects, the empirically exploited variation in GVC positions originates from differences in the product mix of firms within an industry (Herkenhoff et al., 2021). In two alternative specifications, I include respective interaction terms - first, between a firm's upstreamness and exports, and second, between a firm's upstreamness an its exposure to markets characterised by a high EPS.

The main empirical finding confirms the stylised fact that firms occupying upstream GVC positions report higher CO<sub>2</sub> emissions from their production. The effect is statistically significant and economically meaningful. A change in the upstreamness measure by one unit, such as the equivalent of switching from the average GVC position of firms in the *textiles* industry to the *basic metals* industry, increases the estimated CO<sub>2</sub> emissions by 28.15%, CO<sub>2</sub> per unit of sales by 26.87% and CO<sub>2</sub> per unit of value added by 35.39%, respectively. A comparison of firms in very downstream positions, with firms in very upstream positions further illustrates the economically meaningful difference. The estimated CO<sub>2</sub> emissions increase by 63.23%, CO<sub>2</sub> per unit of sales by 60.0%, and CO<sub>2</sub> per unit of value added by even 82.21%. The latter corresponds to an increase from 0.76 kg to 1.39 kg CO<sub>2</sub> emissions per US dollar value added.

Beyond the main finding, I reveal that the relationship between upstreamness and dirty production decreases with exposure to strong environmental regulation. For firms in upstream positions exposed to strong environmental regulation in export markets, the relationship between upstreamness and dirty production even disappears completely. This finding links to the adoption of more efficient technologies by firms aiming to remain competitive in environmentally demanding export markets. Learning-by-exporting, regulation-push, and demand-pull help firms to adoption of these technologies and are especially relevant for dirtier producers in upstream positions, arguably more remote from the technology frontier. For downstream firms, environmental performance deteriorates with exposure to strong environmental regulation in export markets. The finding suggests that, on average, producers in downstream positions specialise in the production of dirty inputs, while producers in upstream positions demonstrate environmental gains from exposure to strong environmental regulation.

Interestingly, I do not find any moderating effect for exports on the relationship between upstreamness and clean production. The latter result suggests that firms located in more upstream positions do not benefit disproportionately from the trade-induced technique effect.

The key results on the relationship between upstreamness and clean production are robust to a variety of alternative specifications. These include the use of an alternative measure of environmental performance by firms, extending the number of covered firms in the estimation sample and the application of a 2-SLS instrumental variable approach. In the latter, I use advertising intensity (advertising expenditure to sales) among firms producing a similar core product. The relevance of the instrument is motivated by a higher incentive for advertising expenditure for firms in downstream positions, such as targeting final consumers. By excluding a firm's advertising spending and sales from the measure, the instrument is exogenously given to a firm and cannot be influenced by its managers or other stakeholders.

The underlying analysis takes place against a backdrop in which policy-makers, keen to foster the transition towards a green economy, are seeking to understand the determinants of clean production. I focus on India, a country that faces multiple challenges. Apart from striving to deal with environmental degradation, India faces other challenges in its efforts to achieve sustainable development, including poverty elimination and energy security. The twin targets of transformation towards a green economy and social development are strongly intertwined. It is imperative to break the detrimental dynamic between economic development and GHG emissions to achieve the ultimate goal of sustainable development. The present study covers the period 2000 to 2014, during which India's share of global  $CO_2$  emissions increased from 4.2% to 6.2%. Significantly, India's absolute  $CO_2$  emissions more than doubled within this period, and in absolute terms, India being the third largest emitter in the world, even though its  $CO_2$  emissions per capita are around 9.5 times less than the equivalent value for the United States (The World Bank, 2019).<sup>1</sup> One approach fostering a global green economic transition is to design trade policy in such a way that rewards clean production along the GVC and fosters a green economic transition. A CO<sub>2</sub> border adjustment tax could represent such an instrument, as it penalises dirtier producers along the GVC by targeting dirtier production with higher tariffs (Aichele & Felbermayr, 2015). However, Shapiro (2021) uncovers an environmental bias in trade policy, where industries in downstream positions can be confronted with higher tariffs vs. industries in upstream positions, even if their production is, on average, more environmentally efficient. Such a policy works against the desired outcome because it subsidises dirty production in upstream industries, thereby undermining the overall target of reducing global  $CO_2$  emissions. My results lend strong support at the firm level to Shapiro's conclusion of trade-induced distortions, pointing to evidence of an environmental bias between relatively dirtier upstream, and cleaner downstream producers.

The remainder of this paper is structured as follows. The next section summarises studies connected to GVCs and the environment, based on which I formulate the testable hypotheses. Section 3 presents the database used in the analysis, the empirical methodology, a description of the variables used, and the descriptive statistics. Next, the empirical results, the instrumental variable approach, and robustness checks are presented. I conclude with a summary of the results and their implications.

### 2 Firm's GVC Positioning and Clean Production

Significant efficiency gains in GHG emissions per unit of output are needed in order to further decouple economic growth and GHG emissions. However, firms cannot fully appropriate the welfare gains of investments in cleaner production techniques, largely because of the double-externality characteristic of these investments (Jaffe, Newell, & Stavins, 2005; Rennings, 2000). Accordingly, firms invest less than the social optimum in GHG emissions reduction. Key determinants in correcting market failures, which boost environmental innovation and investment in cleaner production, are regulationpush, market-pull, technology push, and firm-specific factors (e.g.: Barbieri, Ghisetti, Gilli, Marin, and Nicolli (2016); Brunnermeier and Cohen (2003); Cainelli, Mazzanti, and Montresor (2012); De Marchi (2012); del Río González (2009); Ghisetti, Marzucchi, and Montresor (2015); Ghisetti and Pontoni (2015); Horbach (2008, 2016); Horbach, Rammer, and Rennings (2012); Kesidou and Demirel (2012); Rennings (2000)).

Building on Shapiro (2021), I focus on GVC positioning as a driver of clean production - a driver that has not been considered in prior firm level studies. Shapiro (2021) finds that upstream industries are characterised by reduced environmental efficiency. The reasons suggested for this pattern are multiple. First, firms in upstream industries take raw materials extracted from the ground and transform them. This is more energydemanding than the production of downstream firms, which depend more on relatively cleaner inputs such as labour (Shapiro, 2021). Second, fossil energy inputs such as coal are disproportionately used by the heaviest industries, typically those occupying more upstream positions such as electricity generation, cement manufacturing, and steel blast furnaces (Shapiro, 2021).

There are also other mechanisms, which underpin the relationship between firms' upstreamness and dirty production, beyond those outlined by Shapiro (2021). Marketpull factors affect a firm's decision to invest in clean production (Horbach, 2008). Zhu, Cordeiro, and Sarkis (2012) emphasise that downstream stakeholders - in particular push firms to adopt environmental measures. For these stakeholders, downstream firms are relatively more visible than upstream firms; for instance, downstream products are a ubiquitous part of the daily routine of many consumers. If downstream stakeholders push for sustainable production, this urgency might diminish for less visible products, positioned further upstream the value chain.

Herkenhoff et al. (2021) theoretically and empirically analyse the relationship between the upstreamness and corporate social responsibility (CSR), which serves as another dimension of firms' sustainability in production. They reveal that firms in downstream positions spend comparatively more on CSR. A key reason is that CSR is characterised by incomplete contracts and CSR activities are observable, but not verifiable. As a result, firms have a higher incentive to invest in CSR once their suppliers invest in CSR. Herkenhoff et al. (2021) empirically confirm the prediction of amplifying CSR spending along the GVC, using the Indian Prowess database. It can be concluded from the Herkenhoff et al.'s study that a firm occupying a more downstream position might face a higher incentive to invest in environmentally friendly production techniques - an incentive underpinned by the prioritisation of environmental outcomes by suppliers along the GVC. These environmental-related expenditures share some similarities with CSR, because they are for buyers of intermediates observable, but not verifiable.

Contrary to the mechanisms described earlier, which help to trigger a negative relationship between upstreamness and clean production, a positive relationship can also be argued. Shapiro (2021) points to an environmental bias of trade policy due to lower tariffs for upstream industries, but higher  $CO_2$  emissions per US dollar of output. Bustos (2011) introduces technology change into the Melitz (2003) model and finds that Argentinian firms that face relatively lower tariffs increase revenues by entering foreign markets and are therefore better able to absorb costs of technology upgrading. Kong, Ma, and Qin (2022) show that such technology upgrading is also linked to the improved environmental performance of firms. They find that China's trade liberalisation, following its World Trade Organization accession, significantly reduced the toxic emissions of firms. Combining the results by Shapiro (2021), Bustos (2011), and Kong et al. (2022), firms in upstream positions face lower tariffs and therefore have better access to foreign markets. This, in turn, encourages a firm to introduce technology upgrading and to improve its environmental performance. Nonetheless, viewing the evidence collectively and building on Shapiro (2021), I would expect a negative relationship between upstreamness and clean production to prevail.

However, firms' exports might serve to moderate the negative relationship between upstreamness and clean production. Recent firm level studies have found that exports positively relate to firms' environmental performance (Batrakova & Davies, 2012; Forslid, Okubo, & Ulltveit-Moe, 2018; Girma & Hanley, 2015; Hanley & Semrau, 2022; Richter & Schiersch, 2017). Gutiérrez and Teshima (2018) emphasise the positive impact of trade on technological choice can play a large role, especially for firms in developing countries, because such firms are generally further removed from the technology frontier. Arguably, firms in upstream positions produce in an environmentally less efficiently manner and are more remote from the technology frontier. In line with this, the expected relationship between upstreamness and dirty production might diminish with exports, because firms occupying upstream positions can benefit - in environmental terms - disproportionately from exports.

In general terms, studies investigating the effect of a firm's trade participation on its environmental outcomes in developing or emerging countries are scarce. An exception is Barrows and Ollivier (2021), who similarly use the Prowess database. Interestingly, the environmental metric they apply focusses on the direct  $CO_2$  emissions of firms. The methodology used - calculating the CO2 emissions embodied in the physical energy consumed - is also applied in Barrows and Ollivier (2018) and is novel in the context of an emerging country. However, the concept follows in the spirit of related studies by Richter and Schiersch (2017) and Forslid et al. (2018) who use German and Swedish data, respectively. Barrows and Ollivier (2021) reveal that foreign demand growth increases  $CO_2$ emissions and improves  $CO_2$  efficiency. Interestingly, they also find evidence for technological upgrading at the product level. In sum, foreign demand increases the level of total output, but simultaneous improvements in efficiency, on average, mitigate the scale effect, to the extent of about a half of this effect.

Apart from the expected effect for exports, I expect the magnitude of the relationship between GVC positioning and dirty production to diminish with increased exposure to EPS. Firms in upstream positions that face tough competition in international markets have a disproportionate need to adopt new technologies, in order to improve efficiency and to remain competitive in environmentally strongly regulated countries. In addition, Hanley and Semrau (2022) reveal that firms exposed to strong environmental regulation in import destinations demonstrate higher environmental innovation adoption rates. On average, consumers in countries with stringent environmental regulations have strong preferences for sustainable production and firms are more likely to be equipped with state-of-the-art technologies and skilled labour. Hanley and Semrau (2022) interpret this finding as a mixture of export-induced learning-by-exporting, demand-pull, and regulation-push transmitted through the value chain and augmented by high sustainability standards in import destinations (Brunnermeier & Cohen, 2003; De Loecker, 2007; Horbach, 2008; Newman, Rand, Tarp, & Trifkovic, 2018). However, Acemoglu et al. (2014) emphasise that strong environmental regulation in import destinations may induce specialisation in the production of  $CO_2$ -intensive inputs by firms in developing countries, where the latter face relatively lax domestic EPS. In line with this, the pollution haven hypothesis predicts a shift of dirty industries to developing and emerging countries with less rigorous EPS (Antweiler et al., 2001; Eskeland & Harrison, 2003). The latter can lead to worse environmental performance of these firms. However, it might be the case that these firms still produce in a more environmentally friendly way than their non-exporting domestic peers. Summarising the literature review how GVC participation relate to the environmental performance of firms, I empirically investigate the following hypotheses:

**H1:** A firm's  $CO_2$  emissions increases with upstreamness.

H2: A firm's CO<sub>2</sub> intensity increases with upstreamness.

H3: Exports negatively moderate the link between upstreamness and dirty production.

**H4:** Exposure to stringent environmental policy in export markets negatively moderates the link between upstreamness and dirty production.

The next section presents the methodology, starting with a description of the data used.

### 3 Methodology

#### 3.1 Data Description

I use the firm level Prowess database, merged with the WIOD to test the four hypotheses derived in the previous section. Comprising data on the financial performances of Indian firms, the Prowess data is provided by the Centre for Monitoring the Indian Economy.<sup>2</sup> Designed for academia (and other users), the data primary source information from income statements and balance sheets. Total production in Prowess covers more than 80% of India's GDP (Bos & Vannoorenberghe, 2018).

The empirical set-up spans the period between 2000 and 2014. Prowess data is also available before and after 2014. However, I apply the methodology of Herkenhoff et al. (2021), creating a measure of a firm's GVC position using the WIOD (Timmer et al., 2015).<sup>3</sup> Unfortunately, the latter database is only available for the aforementioned period. Antràs et al. (2012) describe how World Input-Output Tables can be used to calculate a country-industry specific continuous measure of upstreamness. The approach by Herkenhoff et al. (2021) links the industry-specific GVC measure with the product level data of the Prowess database, the latter including information on the capacity, production, and sales, disclosed by firms. Such product level information is rare in the context of an emerging country, going back to the Indian 1956 Companies Act, which mandated to disclose such information in the annual report (Goldberg, Khandelwal, Pavenik, & Topalova, 2010b).

Apart from such essential and not often accessible information at the product level, the coverage of energy consumption is unusual in the context of an emerging country. Firms report on their physical energy consumption, such as quantities of natural gas, electricity, coal, diesel or agricultural by-products consumed. The data availability goes back to a 1988 amendment in the Indian Companies Act, which forces firms to report on energy consumption by energy type. This level of detail makes it possible to calculate the heat content of energy consumption measured in MMBTU. The respective MMBTU of an energy source can be reformulated in terms of its  $CO_2$  content (Barrows & Ollivier, 2018, 2021).

Given its unique data coverage, the Prowess database is widely used in the economics literature, including international economics (e.g., Barrows and Ollivier (2018, 2021); De Loecker, Goldberg, Khandelwal, and Pavcnik (2016); Goldberg, Khandelwal, Pavcnik, and Topalova (2010a); Goldberg et al. (2010b)).

Similar to other studies analysing the determinants of a firm's clean production, I limit the sample to the manufacturing base (Barrows & Ollivier, 2018, 2021; Richter & Schiersch, 2017). The manufacturing base is of particular interest in the context of GVCs and clean production because manufacturing products are comparatively high in  $CO_2$  emissions, compared to service products. Additionally, manufacturing products are more frequently traded (Copeland et al., 2021). The next section presents the empirical strategy used in the analysis.

#### 3.2 Empirical Analysis

Equations 1 and 2 illustrate the two main OLS estimations, with  $CO_2$  emissions and  $CO_2$  intensity used as dependent variables, respectively.

 $ln(CO_2 emissions_{ft}) = \alpha_0 + \beta_1 Upstreamness_{ft} + \beta_2 X_{ft} + \gamma_t + \delta_f + \epsilon_f + \zeta_f, \quad (1)$ 

$$ln(CO_2 intensity_{ft}) = \alpha_0 + \beta_1 Upstreamness_{ft} + \beta_2 X_{ft} + \gamma_t + \delta_f + \epsilon_f + \zeta_f, \qquad (2)$$

 $CO_2 \ emissions_{ft}$  is the natural logarithm of a firm's  $f \ CO_2$  emissions in kilotonnes (kt) in year t derived from its energy consumption during production.  $CO_2 \ intensity_{ft}$ is the natural logarithm of a firm's  $CO_2$  emissions in kt over its sales and value added in US dollars, respectively. The construction of the dependent variables is presented more comprehensively in Section 3.2.1.

 $Upstreamness_{ft}$  is the main independent variable of interest. The value increases with the upstreamness of a firm f in year t. The yearly variation of a firm's upstreamness derives from its product mix, which is described more comprehensively in Section 3.2.2.

 $X_f$  captures different idiosyncrasies of the firm, potential co-determinants of the decision to apply a clean production technology. These drivers can be grouped into regulationpush, market-pull, technology-push, and firm-specific factors.<sup>4</sup>

*EPS* measures the exposure of a firm to foreign markets characterised by strong environmental regulation. On one hand, EPS exposure might connect to the transmission of regulation-push, demand-pull, and learning-by-exporting mechanisms through the value chain (Hanley & Semrau, 2022). On the other hand, domestic firms confronting weaker EPS can specialise in the production of dirty products (Acemoglu et al., 2014). The

construction of EPS is presented in more detail in Section 3.2.3.

Firms that are active in dirtier industries are more likely to trade their outputs (Copeland et al., 2021). However, firm level studies reveal that exporters demonstrate higher energy and emission intensities (Barrows & Ollivier, 2021; Batrakova & Davies, 2012; Forslid et al., 2018; Richter & Schiersch, 2017). A dummy of a firm's *export status* is added to capture the direct participation by a firm in GVCs. *Foreign ownership* captures another domain of GVC participation. Brucal et al. (2019) find that Indonesian firms that are acquired by foreign investors report higher  $CO_2$  emissions but decreased  $CO_2$  intensity than their non-acquired peers. As main reasons for the pattern, the authors highlight technology adoption through knowledge flows associated with foreign ownership. Additionally, they point to superior management practices of foreign-owned firms compared to purely domestic firms. Analogously, a multi-country analysis by Kannen, Semrau, and Steglich (2021) demonstrate empirically that foreign ownership relates to a higher adoption likelihood for green management practices. These practices, in turn, relate to improved environmental performance.

R&D captures a firm's absorptive capacity and technology adoption. Ghisetti et al. (2015) discuss how a firm's R&D links to higher environmental innovation adoption rates, improving the overall environmental performance of the firm. (*ln*) productivity measures a firm's total factor productivity following the method by Ackerberg, Caves, and Frazer (2015). This approach makes it possible to deal with the functional dependence problems that may arise in the approaches used by Olley and Pakes (1996) and Levinsohn and Petrin (2003).<sup>5</sup> Intuitively, a more productive firm is more likely to use state-of-the-art technologies, also associated with an improved environmental performance (Copeland et al., 2021; Shapiro & Walker, 2018).

In line with the importance of the product mix for a firm's environmental performance, three dummies capture the production of non-manufacturing products: dummies for producing agricultural, mining, and service products. I also include a dummy that denotes firms which concentrate exclusively on the production of manufacturing products. The dummies are created based on the product level information component of Prowess. On average, service products require higher levels of labour inputs than manufacturing products. Since labour is a relatively clean input, it is important to control for this aspect. Conversely, agricultural and mining products might require higher energy inputs to extract the raw product. The latter is expected to be, on average, dirtier and more strongly associated with upstream positions (Shapiro, 2021).

A dummy for state ownership captures a possibly lower incentive for state-owned firms to invest in clean production; for example, due to reduced exposure to competition. The variable (ln) assets controls for size effects. Larger firms simply require more energy and have more possibilities to exploit scale effects. The latter improves the attractiveness of investment in CO<sub>2</sub> efficient techniques, since fixed costs can be more widely spread among a greater number of units produced (Forslid et al., 2018). Next, the (ln) age of a firm covers the aspect that young firms might be more innovative compared to relatively older firms.

 $\gamma_t$  covers year fixed effects and  $\delta_f$  industry fixed effects of a firm's core product. The variable  $\epsilon_f$  is a spatial dummy for the state a firm is based, capturing differences such as in environmental regulation between Indian states. Lastly,  $\zeta_f$  denotes the standard errors clustered at the firm level.<sup>6</sup>

Section 4.2 presents an instrumental variable approach to regard for unobservable factors affecting both clean production and the GVC position of a firm. The instrumental variable for the GVC position of a firm considers advertising expenditure (advertising divided by sales) of the five-digit core product a firm produces. The respective measure excludes own advertising expenditure and sales. Next, Section 4.3 includes alternative specifications to shed light on Hypotheses 3 and 4. In these specifications, the upstreamness measure is multiplied by exports and exposure to the EPS of the firm's foreign market, respectively. The interaction terms measure how the export status and EPS in export destinations moderate the relationship between upstreamness and dirty production. Lastly, Section 4.4 covers alternative robustness checks.

#### 3.2.1 Measuring a Firm's Clean Production

A firm's annual  $CO_2$  emissions in absolute and relative terms are used to proxy its clean production. I follow the methodology of Barrows and Ollivier (2018, 2021) to calculate firms' direct  $CO_2$  emissions emitted during production in kt. Also using the Prowess database, Barrows and Ollivier (2018, 2021) use conversion factors provided by the US EPA 2012 Climate Registry Default Emission Factors to transform energy consumption by energy type into  $CO_2$  emissions. Since end-of-pipe carbon capture is not widely used by Indian firms, the  $CO_2$  measure appropriately captures a firm's direct  $CO_2$  emissions (Barrows & Ollivier, 2021).<sup>7</sup> The focus on direct energy inputs, excluding emissions embodied in intermediates or transportation, exclusively targets the production process within a firm.

I use two different approaches to measure  $CO_2$  intensity. First,  $CO_2$  emissions are divided by a firm's annual sales in US dollars, corrected for changes in the stock  $(CO_2/SA)$ . Dardati and Saygili (2021) claim that  $CO_2$  emissions per unit of sales neglects firm-specific heterogeneity, such as the decision of exporters to outsource the production of intermediates. The production of intermediates embodies indirect  $CO_2$  emissions. Dividing a firm's  $CO_2$  emissions by value added corrects for this shortcoming and serves as a direct measure of a firm's  $CO_2$  intensity in production  $(CO_2/VA)$ . I derive a firm's value added by excluding its spending on intermediates from sales.

Furthermore, I exclude observations with the lowest and highest centiles of the annual distribution for the three main outcomes - namely  $CO_2$  emissions,  $CO_2$  emissions per unit of sales, and  $CO_2$  per unit of value added. The latter truncation is comparable to that applied by Barrows and Ollivier (2021). The final sample comprises 17,542 firm-year observations, offering relatively extensive coverage of firms in a country characterised by high and rising  $CO_2$  emissions. However, not all firms report the necessary level of detail on energy consumption. In a robustness check, I significantly extend the sample by focusing on energy costs to measure the environmental performance of firms. In the next section, I introduce the main independent variable of interest: a firm's GVC positioning.

#### 3.2.2 Measuring a Firm's GVC Positioning

Newman et al. (2018) state that the GVC position of a firm might affect CSR investments and empirically capture GVC positions, with the inclusion of industry fixed effects. This approach assumes that a firm's GVC position is a time-invariant variable. However, the GVC position of a firm might change over time, such as due to management decisions on the product mix. Herkenhoff et al. (2021) capture such changes in their firm-specific GVC measure. Their approach builds on the seminal contribution by Antràs et al. (2012) who employ World Input-Output Tables to measure the GVC positions of industries. The industry measure equals to one if an industry sells its products exclusively to end consumers. The value rises to above one if a share is sold as intermediates and increases with distance to final consumption. For example, the value of the measure increases if an industry sells more intermediates to an industry that itself mainly sells to intermediaries.

I follow Herkenhoff et al. (2021) by employing the WIOD to calculate Indian industryspecific GVC positions for the period in question. These GVC positions are merged with the product level Prowess database. Next, the respective GVC positions are weighted by a firm's relative sales in any given year.<sup>8</sup> GVC positions differ between firms within an industry for two main reasons. First, firms differ in their product mix; for example manufacturing firms also sell service products. Second, firms produce similar products, but the relative sale share differs. Generally, I expect a positive relationship between upstreamness and the dependent variables of a firm's dirty production. Also, in line with Herkenhoff et al. (2021), I only regard tradable industries in the calculation of the firmspecific GVC positions, which for instance means excluding the following industries: (i) *human health and social work activities*, (ii) *postal and courier activities* or (iii) *education*. The next section introduces the measurement of exposure towards EPS in export markets.

### 3.2.3 Measuring Exposure to Environmental Policy Stringency in Export Markets

EPS measures a firm's export exposure towards environmentally demanding markets. The creation of the index follows Hanley and Semrau (2022) and exploits the OECD EPS Index (Botta & Koźluk, 2014). The WIOD is used to measure whether exports disproportionately target environmentally stringent markets. I focus on market-related EPS because it - relatively strongly - affects competition and environmental demands (Hanley & Semrau, 2022).

In addition to Hanley and Semrau (2022), and similar to the measure of upstreamness, I weight the industry-specific values with a firm's annual sales in a specific industry. Equation 3 summarises the proxy on EPS in export markets:

$$EPS_{fzt} = \sum_{z=1}^{Z} \frac{sales_{fzt}}{sales_{ft}} \frac{\sum_{k=1}^{n} \frac{EPS_{kt}}{\sum_{k=1}^{n} EPS_{kt}} exports_{zkt}}{\sum_{k=1}^{n} exports_{zkt}}$$
(3)

 $EPS_{jzt}$  is the market-related environmental policy exposure of firm f, producing in industry z at time t. The first term measures the respective share of the firm's f sales in industry z at time t. The shares of a firm sum up to one. The second term captures the EPS exposure of industry z at time t, while regarding the respective stringency of an export destination country k. In line with this,  $EPS_{kt}$  is the market-related EPS in country k at time t and  $exports_{zkt}$  measures the total exports of sector z to country kat time t. n is simply the number of countries covered in the OECD EPS index in a respective year.

Any score above one indicates that exports are generally targeted towards countries with an EPS score above the average, for each year. Accordingly, I expect a negative coefficient of the interaction between upstreamness and EPS, pointing to a negative moderating role in the relationship between upstreamness and dirty production. The next section presents some descriptive statistics, providing insights into the variables of interest.

	(1)	(2)	(2)	(4)	(5)
VADIADIES	(1) N	(2)	(3)	(4)	(3)
VARIABLES	IN	mean	su	111111	max
CO2	17 5 40	00.00	1.001	0.00000	04.000
CO2 emissions (kt)	17,542	92.96	1,261	0.00228	84,296
(ln) CO2 emissions (kt)	17,542	1.836	2.060	-6.082	11.34
CO2/SA	17,542	1.593	4.061	0.00755	149.1
(ln) CO2/SA	17,542	-0.634	1.489	-4.886	5.005
Value added	17,542	36.34	411.4	0.00450	41,441
(ln) CO2/VA	17,542	-0.0404	1.542	-4.505	5.347
Upstreamness	17,542	2.182	0.611	1.415	3.496
Export status	17,542	0.418	0.493	0	1
EPS	17,542	0.964	0.103	0.660	1.512
Foreign ownership	17,542	0.0719	0.258	0	1
SOE	17,542	0.00194	0.0440	0	1
(ln) age	17,542	2.964	0.757	0	4.771
R&D dummy	17,542	0.168	0.374	0	1
(ln) assets	17,542	2.372	1.599	-3.218	10.28
(ln) productivity	17,542	2.504	1.309	-2.924	10.33
Exclusive manufacturing	17,542	0.654	0.476	0	1
Agricultural products	17,542	0.0966	0.295	0	1
Mining products	17,542	0.0156	0.124	0	1
Service products	17,542	0.256	0.437	0	1
Number of products	16,186	3.572	2.976	1	78
Number of GVC industries	16,186	1.643	0.824	1	9
N. L. CC	0.155				
Number of firms	3,155				

 Table 1:
 Summary statistic of covered variables

### **3.3** Descriptive Statistics

Table 1 provides the summary statistics of the dependent and independent variables used in the analysis. To allow for a more straightforward interpretation of the extent to which a firm produces clean outputs, the independent variables are also stated without taking the natural logarithm. The summary statistics cover only those observations used in the empirical analysis.

Among the 17,542 year-firm observations, comprising 3,155 firms, firms emit an average of 92.96 kt  $CO_2$  per year. With a value of 1,261, the standard deviation is significantly higher than the mean, indicating some large emitters. The latter pattern is reasonable because India is home to some very energy-demanding companies, such as producers of aluminium, forgings, paper or cement.

Focusing on the descriptive statistics on the  $CO_2$  intensity, reveals that for one US dollar of sales, 1.59 kg  $CO_2$  is emitted. The median of 0.54 kg is significantly lower, which again points to the role of some dirty producers. The average level of upstreamness is 2.18, with values being between 1.42 and 3.50. A total of 41.8% of firms state that they sell products to foreign markets. In terms of exposure to environmental policy stringency, the average value is below one, at a level of 0.96. A value below one reveals that firms, on average, sell to markets with less stringent environmental policy regulations compared to the average level of stringency covered in the OCED EPS index by Botta and Koźluk

(2014).

In terms of ownership, 7.2% of the observations are foreign-owned, but only 0.19% are state-owned. 16.8% of the observations show some R&D expenditure. Among observations for which product level information is available, firms span on average 1.64 industries in different GVC positions and produce on average 3.57 different products. The latter links to the importance of considering the product mix in the empirical analysis. Overall, 25.6% sell service products other than just their core manufacturing product; 1.56% of the observations sell mining products and 9.7% sell agricultural products that are both on average related to higher emissions and higher scores in the GVC upstreamness measure. 65.4% produce exclusively manufacturing products.

Figure 1 illustrates the development of  $CO_2$  emissions over time, including the respective intensity measures. In addition, the median is illustrated to consider firms with very high  $CO_2$  emissions of some firms.



Figure 1: Development of  $CO_2$  emissions over time

A strongly increasing trend of  $CO_2$  emissions over time is observable. The pattern is valid for the average and the median  $CO_2$  emissions in a respective year. Focusing on average  $CO_2$  emissions per unit of sales reveals a constant trend of average  $CO_2$  intensity, but the median reveals a negative slope. A similar pattern is observable for  $CO_2$  emissions per unit of value added. The latter two patterns indicate that a majority of firms show efficiency gains over time. However, these efficiency gains are offset by some observations with high  $CO_2$  intensities, turning the slope of the averages towards zero.

Table 2 provides insights into the  $CO_2$  emissions and intensities of specific sectors and the respective GVC positions. The table is ordered by decreasing upstreamness.

Table 2: Indust	<u>, , , , , , , , , , , , , , , , , , , </u>		040 00	2 01111001	ons ana	uppered	milloss	
Industry	$  CO_2$	$CO_2$	$CO_2/SA$	$CO_2/SA$	$CO_2/VA$	$CO_2/VA$	Upstr.	Obs.
	average	median	average	median	average	median		
Chemicals	52.76	6.33	1.09	0.47	2.07	0.98	3.19	2,500
Coke & refined petroleum								
products	624.97	0.54	0.57	0.12	1.68	0.36	2.75	93
Basic metals	305.77	11.97	1.89	0.60	3.73	1.31	2.67	2,545
Paper	116.43	29.08	4.62	4.00	9.34	7.71	2.62	977
Other non-metallic mineral	332.66	15.48	3.66	1.57	4.90	2.24	2.34	720
Rubber & plastics products	32.40	2.97	0.68	0.33	1.36	0.73	2.30	1,112
Fabricated metal products	15.24	4.88	0.66	0.41	1.44	0.81	2.28	646
Wood	4.46	1.15	1.92	0.91	3.79	1.61	2.17	23
Printing & reproduction of								
recorded media	0.06	0.06	0.09	0.09	0.09	0.09	2.12	1
Computer electronic & optical								
products	1.40	0.82	0.31	0.11	0.53	0.18	2.11	171
Electrical equipment	6.30	0.80	0.27	0.09	0.60	0.17	2.00	292
Machinery & equipment	11.41	0.74	0.66	0.12	1.05	0.20	1.95	538
Other manufacturing	49.24	0.90	0.94	0.10	1.41	0.23	1.93	72
Other transport equipment	20.72	1.67	0.15	0.06	0.30	0.17	1.82	46
Motor vehicles	8.50	4.16	0.28	0.17	0.51	0.33	1.78	379
Textiles	22.92	7.72	1.57	1.01	2.97	1.80	1.68	3,061
Leather	2.35	1.76	0.62	0.33	1.69	0.48	1.65	28
Wearing apparel	2.73	1.03	0.32	0.09	0.40	0.21	1.65	82
Beverages	41.79	5.96	0.89	0.29	1.48	0.39	1.60	236
Tobacco	94.17	1.05	0.09	0.04	0.12	0.04	1.59	18
Food	45.24	5.59	1.89	0.70	3.54	1.15	1.57	2,713
Pharmaceuticals	33.07	2.91	0.88	0.18	1.31	0.29	1.57	1,289

Table 2: Industry statistic about CO<sub>2</sub> emissions and upstreamness

The coke & refined petroleum products industry shows the highest average  $CO_2$  emissions with 624.97 kt. The industry is in the second most upstream GVC position. However, the median is only 0.54 kt and the dataset only covers 93 observations. In terms of median emissions, the *paper* industry shows the dirtiest production, with  $CO_2$  emissions of 4.62 kt. Interestingly, the *paper* industry is also the industry with the highest means and medians of both  $CO_2$  intensity measures.

The top five most upstream industries have an average median of 12.68 kt, compared to a median of only 3.31 kt among the five most downstream industries. A similar pattern is observable for the mean (286.52.97 kt vs. 43.40 kt). The bias in environmental performance between downstream and upstream industries is also observable in the intensity measures. In terms of  $CO_2$  emissions per US dollar of value added, the top five upstreamness industries emit 4.34 kg, on average, and the top five most downstream industries only emit an average of 1.37 kg. All in all, the above findings show a upstreamness bias towards dirtier production. Notably, the *food* and *beverage* industries also show quite high levels of emissions, with a median of 5.96 kt of the *beverage* industry and 5.59 kt of the *food* industry, respectively. However, both values are still below the average median of the top five upstream industries described above. The next section presents the empirical results.

### 4 Results

The section starts by presenting the results of the main specifications.

#### 4.1 A Firm's GVC Positioning and Clean Production

The first three columns of Table 3 include no industry fixed effects, linking the results closely to the study at the aggregated level by Shapiro (2021). The last three columns include industry fixed effects and limit the exploited variation of upstreamness to differences in the product mix of firms producing in the same main industry. Columns (1) and (4) focus on the determinants of firms' absolute  $CO_2$  emissions, while the remaining columns focus on firms'  $CO_2$  intensities.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	$CO_2$	$CO_2/SA$	$CO_2/VA$	$CO_2$	$CO_2/SA$	$CO_2/VA$
Upstreamness	$0.334^{***}$	$0.289^{***}$	$0.445^{***}$	$0.248^{**}$	$0.238^{**}$	$0.303^{***}$
	(0.055)	(0.053)	(0.055)	(0.104)	(0.108)	(0.107)
EPS	0.062	0.135	0.039	-0.052	0.115	0.022
	(0.273)	(0.269)	(0.270)	(0.238)	(0.233)	(0.228)
Export status	$-0.462^{***}$	$-0.615^{***}$	$-0.581^{***}$	$-0.242^{***}$	$-0.427^{***}$	-0.368***
	(0.060)	(0.059)	(0.058)	(0.055)	(0.054)	(0.054)
Foreign ownership	$-0.423^{***}$	$-0.455^{***}$	$-0.662^{***}$	$-0.284^{***}$	$-0.337^{***}$	$-0.514^{***}$
	(0.118)	(0.120)	(0.122)	(0.109)	(0.110)	(0.112)
R&D dummy	$-0.201^{***}$	-0.320***	-0.448***	-0.009	-0.171**	$-0.254^{***}$
	(0.075)	(0.078)	(0.080)	(0.070)	(0.070)	(0.072)
SOE	1.544 * * *	1.332**	$1.353^{***}$	1.372***	1.195**	$1.191^{***}$
	(0.552)	(0.578)	(0.477)	(0.465)	(0.471)	(0.366)
(ln) productivity	0.083***	-0.179* <sup>**</sup>	-0.331***	0.037*	-0.208***	-0.384***
	(0.022)	(0.021)	(0.021)	(0.021)	(0.020)	(0.020)
(ln) assets	0.998***	0.077***	$0.124^{***}$	$0.947^{***}$	0.037**	$0.074^{***}$
	(0.021)	(0.020)	(0.020)	(0.019)	(0.018)	(0.019)
(ln) age	0.290***	0.112***	0.038	0.200***	0.036	-0.047
	(0.038)	(0.037)	(0.037)	(0.034)	(0.033)	(0.033)
Agricultural products	0.720***	$0.565^{***}$	$0.763^{***}$	0.349***	0.216**	$0.428^{***}$
	(0.115)	(0.119)	(0.120)	(0.105)	(0.109)	(0.111)
Mining products	0.880***	1.104***	$0.926^{***}$	$0.648^{***}$	0.873***	$0.693^{***}$
	(0.199)	(0.197)	(0.196)	(0.192)	(0.198)	(0.190)
Service products	-0.034	-0.203*	-0.128	0.030	-0.126	-0.058
	(0.114)	(0.119)	(0.119)	(0.106)	(0.109)	(0.109)
Exclusive manufacturing	0.172	0.154	0.160	0.093	0.096	0.091
	(0.123)	(0.128)	(0.127)	(0.113)	(0.116)	(0.116)
Observations	17,542	17,542	17,542	17,541	17,541	17,541
R-squared	0.535	0.172	0.202	0.627	0.341	0.365
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummy	No	No	No	Yes	Yes	Yes
State dummy	Yes	Yes	Yes	Yes	Yes	Yes

 Table 3:
 OLS estimation:
 Upstreamness and clean production

Robust standard errors in parentheses (clustered at the firm level) \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1 Upstreamness is positively significant in all six specifications. Interestingly, the coefficients are higher and standard deviations are lower for the specifications without industry fixed effects. However, the coefficients remain significant once industry fixed effects are added. This strongly backs the results and policy conclusions of Shapiro (2021) in the context of an applied micro-level approach, controlling for several firm characteristics. Accordingly, firms producing in upstream industries show a dirtier production, indicated by higher  $CO_2$  emissions and  $CO_2$  emission intensities. Notably, comparing the results of  $CO_2$  intensity per unit of sales with  $CO_2$  intensity per unit of value added reveals stronger results for using value added as a measure of  $CO_2$  intensity. A change in the upstreamness measure by one unit, such as switching from the average GVC position of firms in the *textiles* industry to the *basic metals* industry - increases the estimated  $CO_2$  emissions by 28.15%,  $CO_2$  per unit of sales by 26.87%, and  $CO_2$  per unit of value added

Figure 2 illustrates the estimated level of absolute  $CO_2$  emissions and  $CO_2$  intensities for different GVC positions, once all other variables are held constant at their means. The specifications depicted are Columns (4), (5), and (6) of Table 3.

At the first percentile, the estimated level of  $CO_2$  emission is ln(1.65) at a upstreamness of 1.43, while the effect at the 99<sup>th</sup> percentile is ln(2.14) at a upstreamness of 3.39. Taking the exponential function to obtain the value in kt leads to a magnitude of 5.21 kt and 8.50 kt, respectively. This corresponds to an increase of 63.23%, which is arguably a big difference.

A similar pattern is observable for the estimated level of  $CO_2$  emissions per unit of sales at the respective percentiles. The estimated level at the first percentile is ln(-0.81) and at the 99<sup>th</sup> percentile ln(-0.34). Taking the respective exponential function of the values leads to 0.44 kg CO<sub>2</sub> and 0.71 kg CO<sub>2</sub> emissions per US dollar sold. This corresponds with 60.0% also to an economically meaningful increase.

Using value added as a measure of  $CO_2$  intensity reveals a difference of even 82.21%. The estimated level at the first percentile is  $\ln(-0.27)$  and at the 99<sup>th</sup> percentile  $\ln(0.33)$ . Taking the respective exponential function of the values leads to 0.76 kg  $CO_2$  and 1.39



Figure 2: Estimated relationship between GVC positioning and  $CO_2$  emissions and  $CO_2$  intensities, respectively (Columns (4), (5), and (6) of Table 3)

kg  $CO_2$  emissions per US dollar value added.

All in all, the results statistically and economically back Hypotheses 1 and 2 and show that also within industries, firms in upstream positions produce dirtier than firms in downstream positions.<sup>10</sup> The following section focuses on an instrumental variable approach to deal with possible sources of endogeneity.

#### 4.2 Instrumental Variable Approach

The above-presented results on H1 and H2 are biased if a firm's environmental outcome affects its GVC position or if an omitted variable simultaneously affects a firm's upstreamness and the environmental outcome in production.

An example of reverse causality is where a firm introduces a clean product to the product mix to avoid reputational risks. Generally, consumers might be more likely to claim sustainable production on products they are familiar with, typically in a more downstream GVC position. To this end, the introduction of a clean product paves the way to get closer to customers, while reducing reputational risks.

A relatively similar threat to identification would arise if an omitted variable simultaneously affects GVC positioning and clean production. For instance, a firm's management has social preferences and favours simultaneously B2C (business to consumers) products in downstream positions and introduces a green strategy to improve the environmental footprint in production. In this case, the revealed effect occurs due to the social preferences of the management that are not covered in the firm level data.

I employ an instrumental variable estimation to overcome such endogeneity concerns. By construction, a firm can only influence its GVC position by changes in its product mix. The GVC positioning of each product is already beyond the scope of the management because it is measured at the industry level. However, to exclude any influence by the management, I instrument upstreamness with the natural logarithm of the advertising spending over sales among firms producing a similar main product measured at the five-digit level ((ln) advertising/SA). The instrument does not include the respective spending and sales of the firm.

The instrument should meet two criteria to be valid. First, the instrument needs to be relevant, so the correlation between upstreamness and the instrument should be sufficiently high. I argue that the incentive of a firm for advertising increases along the GVC. Accordingly, firms producing the main product that is closer to final consumption spend more on advertising, on average. Generally, if a correlation is sufficient cannot finally be stated, but the correlation should be significant and a high F-statistic above 104.7 serves as a very conservative rule of thumb for validation (Lee, McCrary, Moreira, & Porter, 2022). Second, a valid instrument meets the exclusion restriction. In line with the exclusion restriction, the instrument should not affect the environmental outcome of a firm, except through the GVC position. The latter is objectively difficult to evaluate. However, I argue that the exclusion of a firm's spending on advertising and sales fulfils the exclusion restriction because a firm does not have any influence on the value of the instrument. Moreover, if a firm decides to extend or reduce the product mix, this normally does not affect the main product. Accordingly, short-term changes due to management

preferences do not enter the estimation and the respective instrumental variable remains exogenously given for a firm.

Table 4 includes the results of a 2-SLS estimation. The first column reports on the first stage, estimating the respective value of a firm's upstreamness. The specification does not include industry fixed effects because there is no sufficient correlation between the instrument and upstreamness at the first stage once the estimation focuses on the within industry variation. However, this is not completely surprising, because it is quite restrictive in the light of a high correlation of average advertising spending over sales estimated at the five-digit product level within an industry. Accordingly, the 2-SLS estimation does closely link to the specifications covered in Columns (1)-(3) of Table 3, overall linking to the results at the aggregated level by Shapiro (2021). Columns (2)-(4) of Table 4 refer to the main results of the 2-SLS estimation, including the estimated values of upstreamness as an instrument for firms' GVC positions.

Table 4: 2-5L5 Estimation								
	(1)	(2)	(3)	(4)				
	Upstream.	CO2	CO2/SA	CO2/VA				
VARIABLES	OLS	2-SLS	2-SLS	2-SLS				
(ln) advertising/SA	-0.123***							
( ), O,	(0.007)							
Upstreamness	· · · ·	1.632***	$1.215^{***}$	$1.854^{***}$				
•		(0.169)	(0.152)	(0.172)				
EPS	$-2.874^{***}$	3.905***	2.889***	4.162***				
	(0.102)	(0.573)	(0.520)	(0.587)				
Export status	0.075***	-0.540***	-0.670***	-0.663***				
*	(0.023)	(0.070)	(0.066)	(0.071)				
Foreign ownership	$0.166^{***}$	-0.509***	-0.512***	-0.759***				
0	(0.046)	(0.136)	(0.133)	(0.144)				
R&D dummy	-0.005	-0.060	-0.209**	-0.300***				
-	(0.031)	(0.090)	(0.087)	(0.096)				
SOE	0.178	1.387***	1.218**	ì.181* <sup>*</sup>				
	(0.132)	(0.519)	(0.549)	(0.523)				
(ln) productivity	0.018**	0.029	$-0.215^{***}$	-0.388***				
	(0.008)	(0.026)	(0.024)	(0.026)				
(ln) assets	-0.012*	0.990***	0.073***	0.116***				
	(0.007)	(0.023)	(0.022)	(0.024)				
(ln) age	-0.029**	0.342***	$0.154^{***}$	0.103**				
	(0.013)	(0.044)	(0.041)	(0.044)				
Agricultural products	-0.294 ***	1.124***	0.864***	1.202***				
	(0.037)	(0.132)	(0.128)	(0.137)				
Mining products	0.103**	0.720***	0.988***	$0.740^{***}$				
	(0.043)	(0.188)	(0.185)	(0.187)				
Service products	0.053	-0.060	-0.225*	-0.163				
	(0.032)	(0.115)	(0.116)	(0.120)				
Exclusive manufacturing	-0.032	$0.274^{**}$	0.221*	$0.254^{*}$				
	(0.036)	(0.125)	(0.126)	(0.129)				
Observations	16,803	16,803	16,803	16,803				
R-squared	0.410							
F-stat	283.69							
Year dummy	Yes	Yes	Yes	Yes				
Industry dummy	No	No	No	No				
State dummy	Yes	Yes	Yes	Yes				

Table 4: 2-SLS Estimation

Robust standard errors in parentheses (clustered at the firm level) \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

The results of the first stage reveal that (ln) advertising/SA significantly negatively correlates with a firm's upstreamness. Also, the F-statistic is 283.69 clearly above stan-

dard thresholds. Both patterns provide a high level of confidence that the instrument is relevant.

The positive relationship between firms' upstreamness and dirty production remains unchanged in all specifications. In all specifications, the positive effect is significant at the one-percent level, which again strongly supports H1 and H2.

As stated in Hypotheses 3 and 4, the negative effect of upstreamness on the environmental outcome might differ with a firm's export status and exposure to EPS. The next section analysis the validity of these hypotheses.

# 4.3 The Moderating Roles of Export Status and Exposure to EPS

Columns (1) to (3) of Table 5 show the results of an interaction term between upstreamness and export status. Columns (4)-(6) include the interaction term between upstreamness and exposure to EPS.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	CO2	CO2/SA	CO2/VA	CO2	CO2/SA	CO2/
Upstroomnoss	0.225**	0.206*	0.270**	0 088***	0 768***	0.886*
Opstreamness	(0.112)	(0.114)	(0.114)	(0.208)	(0.280)	(0.20
Export status	-0.364**	-0.595***	-0 543***	-0.242***	-0 427***	-0.368
Export status	(0.181)	(0.174)	(0.177)	(0.055)	(0.054)	(0.05
EPS	-0.045	0.124	0.032	1 614***	1 307**	1 335
	(0.237)	(0.233)	(0.228)	(0.609)	(0.581)	(0.59
Upstreamness x Export status	0.056	0.077	0.080	(0.000)	(0.00-)	(0.00
o potroammood in Emport Statud	(0.081)	(0.077)	(0.079)			
Upstreamness x EPS	(0.001)	(0.011)	(0.010)	-0.809***	-0.579**	-0.637
1				(0.298)	(0.277)	(0.28)
Foreign ownership	$-0.284^{***}$	-0.337***	-0.514***	-0.282***	-0.336***	-0.513
0	(0.109)	(0.110)	(0.111)	(0.109)	(0.110)	(0.11)
R&D dummy	-0.011	-0.174**	-0.256***	-0.011	-0.172**	-0.255
	(0.070)	(0.070)	(0.072)	(0.070)	(0.070)	(0.07
SOE	1.374***	1.198***	1.195***	1.370***	1.194**	1.190
	(0.460)	(0.463)	(0.359)	(0.468)	(0.473)	(0.36)
(ln) productivity	0.037*	-0.207***	-0.383***	$0.037^{*}$	-0.208***	-0.384
	(0.021)	(0.020)	(0.020)	(0.021)	(0.020)	(0.02)
(ln) assets	0.947 * * *	0.038**	0.075 * * *	0.947 * * *	0.038**	$0.074^{3}$
	(0.019)	(0.018)	(0.019)	(0.019)	(0.018)	(0.01)
(ln) age	$0.199^{***}$	0.035	-0.048	0.201***	0.036	-0.04
	(0.034)	(0.033)	(0.033)	(0.034)	(0.033)	(0.03)
Agricultural products	0.351***	0.219**	0.431***	$0.353^{***}$	0.219**	$0.430^{3}$
	(0.106)	(0.109)	(0.111)	(0.106)	(0.109)	(0.11)
Mining products	$0.651^{***}$	$0.878^{***}$	$0.698^{***}$	$0.637^{***}$	$0.866^{***}$	$0.685^{\circ}$
	(0.192)	(0.198)	(0.190)	(0.192)	(0.197)	(0.19)
Service products	0.032	-0.123	-0.054	0.034	-0.123	-0.05
	(0.106)	(0.110)	(0.110)	(0.106)	(0.109)	(0.10)
Exclusive manufacturing	0.097	0.101	0.096	0.094	0.096	0.09
	(0.114)	(0.116)	(0.116)	(0.113)	(0.116)	(0.11)
Observations	17,541	$17,\!541$	17,541	17,541	17,541	17,5
R-squared	0.627	0.341	0.365	0.627	0.341	0.36
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
State dummy	Yes	Yes	Yes	Yes	Yes	Yes

Table 5: OLS estimation: Moderating effects of export status and EPS on upstreamness

Robust standard errors in parentheses (clustered at the firm level) \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

While the overall positive relationship between upstreamness and dirty production

remains significant in all specifications, the interaction term of upstreamness and export status is not significant in any specification. Accordingly, there is no significant different slope for the relationship between upstreamness and dirty production depending on the export status of a firm observable. This finding does not back H3, pointing to possible differences in the magnitude of the technique effect along the value chain.

Conversely, the results of Columns (4)-(6) reveal a moderating role of demanding export markets on a firm's environmental performance. The interaction term between upstreamness and EPS is significant in all specifications, varying between five-percent and one-percent significance. This finding indicates that the main relationship between upstreamness and dirty production is conditional on the interaction because the positive slope diminishes with an increasing level of exposure to strong environmental regulation in foreign markets.

Figure 3 illustrates the moderating role of EPS on the relationship between upstreamness and  $CO_2$  emissions per unit of value added (Column (6)).<sup>11</sup> The upper graph illustrates the predicted  $CO_2$  per unit of value added depending on upstreamness for given levels of EPS. The lower graph illustrates the predicted  $CO_2$  intensities depending on EPS for given levels of upstreamness.

An EPS score of 1.5 links to very strong environmental regulation in export destination markets. Given that firms face such a strong regulation, the slope of upstreamness is slightly negative, even if it is not significant. Conversely, an EPS score of very low 0.7 links to a strongly positive slope. The respective coefficient of upstreamness is 0.44 significant at the one-percent level. Holding the EPS score constant, it is also possible to derive the economic significance. For example, for firms exposed to weak environmental regulation in foreign markets (EPS = 0.7), a one-unit change in the upstreamness measure is associated with an increase of CO<sub>2</sub> emissions of 52.46%, CO<sub>2</sub> emissions per unit of sales of 43.72%, and CO<sub>2</sub> emissions per unit of value added of 55.29%.<sup>12</sup>

Interestingly, the relationship between EPS and dirty production becomes significantly positive once the interaction term between upstreamness and EPS is added. Also, the relationship between EPS and clean production is conditional on firms' GVC



Figure 3: Predicted (ln)  $CO_2$  per unit of value added for different combinations of upstreamness and EPS

positions. As the lower graph of Figure 3 illustrates, firms'  $CO_2$  intensity increases with EPS for firms in very downstream positions (upstreamness = 1.4). However, the derived coefficient of 0.44 is only significant at the 10-percent level. For firms in very upstream positions (upstreamness = 3.4), the coefficient turns negative to 0.83, again being significant only at the 10-percent level. In line with the only slight significance and given that a one-unit change of EPS relates to a difference in exposure going slightly beyond the difference of the minimum and maximum value observed in the sample, the economic significance should not be over-interpreted.<sup>13</sup> Still, these relationships indicate some specialisation in dirty production in downstream positions.

All in all, the results revealed in Table 5 strongly back Hypothesis 4 and its economic relevance. This findings indicates that the relationship between upstreamness and dirty production diminishes with EPS for firms in upstream positions. Accordingly, firms in upstream positions seem to environmentally benefit outstandingly from exposure to strong environmental regulations in foreign markets. This insight links to the adoption of more efficient production techniques to remain competitive with firms in environmentally demanding markets, trade-induced learning-by-exporting effects, demand-pull, and regulation-push especially important for firms being further removed from the technology frontier in upstream positions. Conversely, firms in downstream positions show dirtier production with increased exposure to strong environmental regulation in foreign markets. The latter links to a specialisation in dirty production in line with Acemoglu et al. (2014). The next section focuses on the robustness of the key results.

#### 4.4 Robustness

Unfortunately, not all firms report on their energy consumption in physical energy units. Accordingly, it is only possible to calculate annual  $CO_2$  emissions for a subset of firms covered in Prowess. However, most firms report on their energy spending in US dollars. Energy costs are widely used in the literature to measure firms' environmental performances, for example, Eskeland and Harrison (2003) and Batrakova and Davies (2012). Cole, Elliott, and Strobl (2008) also use energy costs to proxy firms' environmental performance. However, they emphasise that their dependent variable should ideally capture a firm's emissions. I follow this suggestion in the main specifications because there are two main drawbacks of using energy costs. First, price changes in energy costs result in changes on the environmental performance measure, even if it does not affect a firm's environmental performance. Second, switching to cheaper energy sources results in an improvement of the measure, even though the newly used energy source can show a worse or better  $CO_2$  footprint. Nonetheless, both proxies are highly correlated, which motivates this robustness check. Table 6 reports on the results once energy costs are used to calculate firms' clean production in absolute and relative terms. Columns (1)-(3)connect to the main specifications on the relationship between upstreamness and dirty production discussed in Section 4.1. Columns (4)-(6) link to the main results outlined in Section 4.3 on the moderating role of exposure to EPS.

The relationship between upstreamness and environmental performance is statistically significant at the one-percent level in all six specifications. In addition, the interaction

	. ULS	esumati	$0 \Pi$ . $\Pi 0 D$	ustness (	meeks				
	(1)	(2)	(3)	(4)	(5)	(6)			
VARIABLES	ENE	ENE/SA	ENE/VA	ENE	ENE/SA	ENE/VA			
Upstreamness	$0.344^{***}$	$0.340^{***}$	$0.424^{***}$	$1.089^{***}$	$0.829^{***}$	$1.012^{***}$			
	(0.069)	(0.064)	(0.072)	(0.210)	(0.195)	(0.214)			
EPS	0.141	$0.236^{**}$	0.207*	$1.723^{***}$	$1.274^{***}$	$1.455^{***}$			
	(0.127)	(0.119)	(0.123)	(0.402)	(0.370)	(0.395)			
Upstreamness x EPS				-0.798***	$-0.524^{***}$	-0.630***			
				(0.194)	(0.180)	(0.193)			
Export status	$0.145^{***}$	$-0.152^{***}$	-0.076**	$0.145^{***}$	$-0.152^{***}$	-0.075**			
	(0.034)	(0.032)	(0.032)	(0.034)	(0.032)	(0.032)			
Foreign ownership	0.154**	-0.025	-0.167 * * *	0.155**	-0.024	-0.166***			
	(0.062)	(0.060)	(0.062)	(0.062)	(0.060)	(0.062)			
R&D dummy	$0.069^{*}$	-0.121***	-0.191***	0.069*	-0.122***	-0.191***			
	(0.039)	(0.038)	(0.039)	(0.039)	(0.038)	(0.039)			
SOE	0.746***	0.678 * * *	0.779***	$0.747^{***}$	$0.678^{***}$	0.779***			
	(0.264)	(0.220)	(0.166)	(0.265)	(0.221)	(0.166)			
(ln) productivity	-0.014	-0.301***	-0.487***	-0.014	-0.301***	-0.486***			
	(0.014)	(0.012)	(0.014)	(0.014)	(0.012)	(0.014)			
(ln) assets	$0.812^{***}$	-0.121***	-0.073* <sup>**</sup>	$0.812^{***}$	-0.121***	-0.073***			
	(0.011)	(0.010)	(0.010)	(0.011)	(0.010)	(0.010)			
(ln) age	$0.212^{***}$	0.066***	0.003	0.213 * * *	0.067***	0.004			
	(0.019)	(0.018)	(0.019)	(0.019)	(0.018)	(0.019)			
Agricultural products	0.561***	0.432***	0.614***	0.565***	$0.435^{***}$	0.617 * * *			
0	(0.077)	(0.072)	(0.077)	(0.077)	(0.072)	(0.077)			
Mining products	0.218**	0.409***	0.280***	0.206**	0.402***	0.270**			
01	(0.104)	(0.102)	(0.105)	(0.104)	(0.103)	(0.105)			
Service products	0.082	0.006	0.034	0.086	0.009	0.038			
-	(0.080)	(0.077)	(0.078)	(0.080)	(0.077)	(0.078)			
Exclusive manufacturing	0.027	$0.135^{*}$	0.115	0.027	$0.135^{*}$	0.116			
0	(0.082)	(0.080)	(0.080)	(0.083)	(0.080)	(0.080)			
	()	(/	()	()	()	()			
Observations	42,762	42,762	42,762	42,762	42,762	42,762			
R-squared	0.632	0.375	0.416	0.632	0.375	0.416			
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes			
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes			
State dummy	Yes	Yes	Yes	Yes	Yes	Yes			
Robust standard errors in parentheses (clustered at the firm level)									

Table 6: OLS estimation: Robustness checks

bust standard errors in parentheses (clustered at the firm le \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

between upstreamness and EPS is significant in all three specifications. To summarise, the robustness checks back prior results on H1, H2, and H4. Accordingly, firms in downstream positions show significantly cleaner production and exposure to strong environmental regulation in export markets diminishes the negative effect of upstreamness on clean production. The last section concludes the overall results of the study.

### 5 Conclusion

A large share of India's population still lives in poverty. Economic growth is essential to eliminate poverty but corresponds to a higher energy demand. Higher energy demand strongly correlates to higher  $CO_2$  emissions, a nexus that has not been sufficiently broken. Even though the per capita  $CO_2$  emissions of India are relatively low on global scale, the country is the third largest global emitter of  $CO_2$ . Although industrialised countries are responsible for the majority of historical  $CO_2$  emissions, successes in developing countries, including India, are crucial if there is any hope of fulfilling the Paris Agreement's target of limiting global warming to well below  $1.5^{\circ}$ Celsius. This is mainly because most emissions growth originates from this subset of world's economies (Copeland et al., 2021).

To this end, regional and global decision makers need to understand the determinants of firms' environmental efficiency in production. Shapiro (2021) reveals that industries in downstream GVC positions emit less  $CO_2$  per unit of output. However, even in narrowly defined industries, firms differ substantially, for instance in their productivity and product mix. I empirically contribute to the literature on the understanding of the drivers of clean production, more precisely on the question of how firms' GVC positioning relates to its environmental outcome.

The derived results show that Indian manufacturing firms occupying upstream GVC positions emit significantly more  $CO_2$  and report worse  $CO_2$  intensities, measured as  $CO_2$  per unit of sales, and as  $CO_2$  per unit of value added. A change in the upstreamness measure by one unit - such as switching from the average GVC position of firms in the *textiles* industry to the *basic metals* industry - increases the estimated  $CO_2$  emissions by 28.15%,  $CO_2$  per unit of sales by 28.87%, and  $CO_2$  per unit of value added by 35.39%. These key findings are robust against a 2-SLS estimation.

In addition, the empirical results reveal that exposure to foreign EPS negatively moderates the relationship between upstreamness and dirty production. Firms in upstream positions are, on average, further removed from the technology frontier and have to adopt more efficient production techniques to remain competitive in environmentally demanding markets abroad. These upstream firms can also disproportionately benefit from trade-related positive drivers of their clean production such as learning-by-exporting, regulation-push, and demand-pull. Interestingly, for firms in downstream positions, environmental performance deteriorates with increased exposure to EPS in export markets - a finding linked to specialisation in dirty production (Acemoglu et al., 2014). Notably, the negative relationship between upstreamness and clean production does not differ with the firm's export status.

My study contributes to the understanding of the determinants of firms' clean production in developing countries. Copeland et al. (2021) emphasise that the relationship between upstreamness and dirty production is observable in countries at all stages of development. I would expect similar results using firm level data for advanced countries. However, I expect that the moderating role of EPS in foreign markets might distinguish between studies using data for advanced countries. Firms occupying upstream positions and already facing strong domestic environmental regulation might not have to step up to new production techniques, even if they encounter strong EPS abroad. Such an analysis could represent part of a future research agenda. Moreover, in this paper, I have not touched on the role of indirect emissions. The relative importance of indirect emissions amplifies with downstreamness and it would be interesting to investigate whether the revealed upstreamness is also observable for indirect emissions (Copeland et al., 2021).

The key results have different implications for a firm's management and political decision makers. First, management can improve the overall environmental performance by introducing relatively clean products in downstream positions. A switch of the product mix to include cleaner products does not require any technological adoption and might be an attractive tool for the management to improve the general perception of stakeholders on sustainable production, such as when publishing statistics relating to  $CO_2$  emission intensity, for outside investors. Arguably, the switch to downstream products is a form of greenwashing because it does not require the firm to make any fundamental changes in its processes - merely, in its product mix. Accordingly, this strategy is open to criticism by more sophisticated kind of stakeholder - those able to monitor the firm's performance at the product level.

Second, regional decision makers have an incentive to attract downstream industries to improve their regional  $CO_2$  balance sheet. However, on a global scale, the negative effect of GHG emissions on global warming does not depend on the location of emissions. Accordingly, and in line with the environmental bias of trade policy revealed by Shapiro (2021), tariffs for downstream industries should be reduced, bolstering support for them relative to upstream industries. Currently, the pattern is completely reversed, leading to an implicit subsidy for the relatively  $CO_2$ -intensive upstream industries.

Third, regulators should position the spotlight on the  $CO_2$  intensity of upstream industries, where more energy is required to produce one unit of value added. The issue is

how to incentivice consumers and other stakeholders interested in sustainable production, to expend higher efforts to monitor these environmental outcomes for upstream GVC positions, where end-consumers may be less directly invested in the products. Some of these upstream industries are tagged as hard to decarbonise, e.g. chemicals, cement or steel production. However, this does not preclude regulators from applying specific measures. One approach would be to reduce or eliminate the implicit subsidy for upstream industries by decreasing tariffs for downstream positions. Another, would be to establish an appropriate  $CO_2$  price mechanism and to incentivise environmentally-friendly inputs such as renewable energies, renewable natural gas or green hydrogen. A judicious use of these measure could accelerate the green transition of these industries.

Lastly, monitoring global efforts on  $CO_2$  reduction, multilateral institutions should consider differences in the average GVC positions of individual countries. Upstream industries generally report reduced environmental efficiency, but they are integral to GVCs, whose final production stages are often located in other – more developed - countries. The latter depend on these inputs. Accordingly, these countries are indirectly contributing to global pollution, when the GVC is viewed in its entirety. A comprehensive assessment of environmental footprints - consumption-based evaluation vs. production-based evaluation - could help overcome this distortion. Additionally, the application of a price which would correct for the environmental externality, for example  $CO_2$  border adjustment taxes, would provide an incentive to downstream firms to push for sustainable production along the entire GVC.

## Appendix



Table 7: Correlations of dependent variables and upstreamness (1) (2) (3) (4)

Figure 4: Predicted (ln)  $\rm CO_2$  emissions for different combinations of upstreamness and EPS



Figure 5: Predicted (ln)  $CO_2$  emissions per unit of sales for different combinations of upstreamness and EPS

### Notes

<sup>1</sup>Downloaded on 20 December 2019

<sup>2</sup>The data were downloaded from https://prowessdx.cmie.com/ on the 26th of November 2019. I downloaded the data in US dollars and deflated all monetary variables using the World KLEMS data. The KLEMS data were downloaded from http://www.worldklems.net/data.htm, using the sheet GO\_P, which takes 2010 prices as the reference price. Last download on 21 September 2018.

<sup>3</sup>I also employ the WIOD Release 2016, including Input-Output Tables for 28 European countries and 15 other major economies (Timmer et al., 2015), downloaded from http://www.wiod.org/home

 ${}^{4}$ For a literature review on the drivers of environmental innovation check Barbieri et al. (2016) and del Río González (2009).

<sup>5</sup>I applied the Stata command developed by Manjón, Manez, et al. (2016). To derive a firm's productivity, the firm's value added is used as a dependent variable. In addition, standard errors are robust, a firm's assets are used as state the variable, the wage bill is used as the free variable, and costs on intermediates is used as the proxy.

 $^{6}$ I decided against the inclusion of firm fixed effects because of the limited within variation of *upstreamness*. Accordingly, the independent variable has only limited power to explain within firm variation in CO<sub>2</sub> emissions over time.

<sup>7</sup>I updated the replication files, generously supplied by Barrows and Ollivier (2021), for the purposes of the present study. See Barrows and Ollivier (2018, 2021) for a detailed discussion on data construction and the quality of the derived firm level  $CO_2$  emissions.

<sup>8</sup>Linking product level information with industry-specific GVC information is in line with Chor, Manova, and Yu (2021) who exploit Chinese data to analyse a firm's performance along the global production line. To this end, they weight the GVC positions of a firm's product mix with a product's export and import share.

<sup>9</sup>The derived change in percentage is calculated by solving:  $(\exp(\text{coefficient})-1)*100$ .

<sup>10</sup>Going beyond upstreamness and taking Column (6) as a benchmark to measure the drivers of firms' clean production reveals that exporters, foreign-owned firms, more productive firms and firms active in R&D show lower  $CO_2$  intensity. Conversely, state-owned firms and firms producing mining or agricultural products produce more  $CO_2$ -intensive. No effect is observable for purely manufacturing firms or service firms. Lastly, exposure to *EPS* does not relate to any changes in a firm's clean production.

<sup>11</sup>The respective graphs for  $CO_2$  emissions (Column (4)) and  $CO_2$  emissions per unit of sales (Column (5)) are part of the Appendix (Figures 4 and 5).

<sup>12</sup>For example, the respective coefficient of  $CO_2$  emissions is calculated by solving: 0.988-0.809\*0.7=0.42. The effect is given by:  $(\exp(0.42)-1)*100=52.46$ .

<sup>13</sup>For example, for firms in very downstream positions (upstreamness = 1.4), a one-unit change in the

EPS measure is associated with an increase of  $CO_2$  emissions of 61.83%,  $CO_2$  emissions per unit of sales of 64.28%, and  $CO_2$  emissions per unit of value added of 55.77%. Turning to very upstream positions, the sign of the relationship between EPS and clean production shifts positively. For example, for firms in very upstream positions (upstreamness = 3.4), a one-unit change in the EPS measure is associated with a decrease of  $CO_2$  emissions of 67.91%,  $CO_2$  emissions per unit of sales of 48.4%, and  $CO_2$  emissions per unit of value added of 56.43%.

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