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International Engagement and the Greenness of Manufacturing Firms[*]

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Abstract

This paper examines how international engagements shape heterogeneity in the greenness of Japanese manufacturing firms. Using a new firm-level dataset, we construct intensity-based greenness indicators distinguishing between the greenness of market facing products and the greenness of more governance-driven production processes. Our empirical results are three-fold. First, green activity is widespread across Japanese manufacturing sectors but is predominantly process-oriented, with the greenest firms concentrated in a small subset of industrial activities. Second, greenness is not linked to internationalization in general, but to firms being embedded in global value chains (GVCs), particularly in Western oriented networks, and this association is stronger for green processes. Third, we identify a vulnerability whereby product greening does not attenuate tariff induced sales losses among internationally engaged firms, and green processes do appear to amplify tariff exposure, especially for GVC participants. Overall, the results highlight that going green is multidimensional and that environmental process compliance interacts with GVC integration in shaping firms' resilience to trade policy shocks under a trend towards further geoeconomic fragmentation.

Keywords: GVC; green transition; trade policy; Japanese manufacturing
JEL classification: F14; F18; Q55; Q56

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1 Introduction

Climate mitigation has placed the decarbonization of manufacturing at the center of the global policy agenda (IPCC 2022). However, modern manufacturing is increasingly organized through participation in global value chains (GVCs) which means that a firm's process of decarbonization or green transition may be shaped not only by domestic regulation but also by international engagement via buyer governance structures, codified standards, and verifiable compliance requirements (Copeland et al. 2022, Gereffi et al. 2005). Relatedly, a firm's decision to become greener may also affect the degree to which it becomes embedded in production networks which, in turn, will impact the firm's exposure to external shocks.

The purpose of this paper is to better understand the relationship between a firm's international links and the greenness of their products and production processes and whether integration within GVCs is associated with firms' greenness and how international engagement impacts a firm's vulnerability to, or resilience against, external shocks. To this end, we study firms in Japan's manufacturing sector, which provides a useful setting to investigate these mechanisms because the country sits at the intersection of dense cross-border production networks and heterogeneous environmental governance regimes (IDE-JETRO 2011, OECD 2023). As a supply-chain hub that links Asian production networks with Western final-goods markets, Japanese firms face both coordination-efficient regional links and governance-intensive relationships tied to stringent standards and compliance (Nishitani 2010, Meng et al. 2019). As such, Japanese manufacturing firms are exposed on both internal and external pressure to become greener but also operate in a highly competitive region where being integrated into GVCs is central to economic performance.

The existing research has tended to show that international engagement is associated with cleaner production and an improved environmental performance of firms (e.g., Richter & Schiersch 2017, Forslid et al. 2018, Banerjee et al. 2021, Rodrigue et al. 2024). However, two limitations remain salient for understanding the greenness of a firm's products and production processes. First, internationalization is frequently measured using coarse participation indicators, making it difficult to distinguish across modes of engagement and the location of different trade partners.(Cherniwchan et al. 2017, Copeland et al. 2022). Second, the greenness of firms is often proxied by aggregate measures that do not allow a distinction to be made between product-side and process-side greenness, the latter being more readily codified, verified, and enforced through supply-chain governance (Gereffi et al. 2005, Delmas & Montiel 2009, Arimura et al. 2011).

The contribution of this paper is to use the new firm-level dataset to address the challenges identified in the previous literature and document the relationship between international engagement and the greenness of Japanese manufacturing firms. More specifically, in the first stage we use the recent firm-level dataset of Japanese manufacturers to measure at a highly disaggregated level a firm's: (1) greenness and (2) international activities. The data allow us to distinguish between product-oriented and process-oriented greenness and to capture the degree to which a firm is integrated into supply-chains and by trading partner that enables us to disentangle Asia-specific from Western-oriented networks. Hence, we are able to investigate whether international engagement is associated with a firm's greenness and which forms of international engagement matter more and for which margins of greenness. In the second stage, following the April 2025 Trump tariff shock, we examine whether international engagement amplifies firms' vulnerability to trade-policy shocks or, enhances their resilience.

To briefly summarize our results, we find that the engagement of firms in the green transition is widespread but uneven. Roughly half of Japanese manufacturing firms undertake some form of green activity, yet greenness is predominantly process-oriented rather than product-oriented and is typically limited in intensity, with high-intensity concentrated in a relatively small subset of firms. This pattern is also heterogeneous across sectors, with green activities more prevalent and more intensive in energy- and material-intensive sectors. Second, green firms are systematically more likely to participate in international markets than non-green firms, but this participation advantage is driven primarily by trade and supply-chain linkages within Asia. Distinct from this participation margin, greenness is not associated with internationalization per se but is instead linked to the degree of international engagement primarily through firms integrated into Western-oriented supply-chain networks. Third, we show that greenness shapes firms' exposure to trade-policy shocks. While product-side greenness plays a limited role in moderating the relationship between international activity and tariff-induced sales losses, process-side greenness amplifies tariff exposure among internationally engaged firms, especially those integrated into GVCs. Overall, our results suggest a possible trade-off between greater environmental processes and vulnerability to trade-policy shocks for firms embedded in complex cross-border production networks.

To put the results in context, our study contributes to the existing literature in three main ways. First, we extend the trade-environment literature by showing that the relationship between globalization and firm-level greenness depends on the nature of a firm's internationalization profile. Although Richter & Schiersch (2017), Forslid et al. (2018), Banerjee et al. (2021), Rodrigue et al. (2024) show that, on average, exporters are cleaner, much of this work relies on coarse export status or export intensity measures that abstract from the structure of cross-border relationships. By examining GVCs by partner regions, we are able to show that Asia-centered links account for the majority of Japanese manufacturing firms' international participation at the extensive margin, while substantive and intensive greenness is concentrated among firms embedded in Western-oriented supply-chain networks. The evidence therefore points to governance and compliance channels within supply chains as central mechanisms linking international engagement to green transformation.

Second, by disentangling greenness by products and production processes we extend the literature that has previous relied on aggregate proxies, such as abatement costs (e.g., Banerjee et al. 2021, Rodrigue et al. 2024) or emissions-based measures (e.g., Cole et al. 2013, Richter & Schiersch 2017, Forslid et al. 2018, Rodrigue et al. 2024), that do not cleanly separate market-facing product adjustments from governance-intensive process upgrading (OECD 2008). Using intensity-based measures we show that process-oriented greenness is the more prevalent and is more closely associated with internationalization. This distinction helps reconcile the mixed findings in the previous literature by demonstrating that the relationship between international engagement and "green" outcomes is not uniform, but depends on the type of greenness being considered.

Finally, we contribute to research on the green transition and GVC governance by documenting a potential trade-off between greening production processes and trade policy resilience (Delmas & Montiel 2009, De Marchi et al. 2013). When examining the relationship between international engagement and tariff-induced sales losses, we find that product-side greenness plays a negligible role in moderating firms' exposure. In contrast, process-side greenness amplifies tariff exposure among internationally engaged firms, with the effect concentrated in those integrated into GVCs. We attribute this vulnerability to a "lock-in" mechanism whereby audit compliance, required for intensive process greening, necessitates relationship-specific investments in, for example, specialized equipment, the use of certified inputs, and stable supplier ties (Gereffi et al. 2005, Antràs & Chor 2013). Such investments may reduce input substitutability and raise switching costs, deepening dependence on specific cross-border nodes. Consequently, the very governance arrangements that ensure long-run process compliance may inadvertently reduce short-run adjustment capacity against trade-policy headwinds, implying a potential trade-off for firms pursuing process-oriented greening within integrated GVCs.

The remainder of the paper is organized as follows. Section 2 develops the conceptual framework and derives the empirical hypotheses. Section 3 describes the data and key measures. Section 4 presents the stylized facts, and Section 5 outlines the empirical strategy. Section 6 reports the main results. Section 7 provides additional analysis, and the final section concludes.

2 Conceptual Framework

As production has become increasingly fragmented across borders and organized within GVCs, the nexus between firms' internationalization and green transformation has become central to the trade-environment literature. A widely used framework emphasizes that the environmental effects of trade liberalization work through potentially offsetting scale, composition, and technique channels by expanding aggregate activity, reallocating production across sectors, and reducing emissions intensity through technology diffusion and cleaner production (Grossman & Krueger 1991, Antweiler et al. 2001, Cole & Elliott 2003, Copeland & Taylor 2004). The resulting net impact is therefore theoretically ambiguous and likely heterogeneous across industries, technological trajectories, and policy regimes.

Moreover, as countries differ markedly in environmental regulatory stringency, enforcement capacity, and compliance costs, these forces can translate into the spatial reallocation of pollution-intensive stages of production, yielding empirical patterns consistent with both pollution haven effects and pollution halo channels across regions (Eskeland & Harrison 2003, Levinson & Taylor 2008, Dechezleprêtre & Sato 2017, Cole et al. 2021). Reflecting these ambiguities, recent work increasingly calls for pushing the analysis down to the firm level, examining how trade and GVC integration operate through firms' selection into international markets and subsequent adjustments to their product mix, production processes, and technology adoption that together shape the intensity and direction of the green transformation of the manufacturing sector (Cherniwchan et al. 2017, Copeland et al. 2022).

At the firm level, cross-border engagement entails fixed costs and capability thresholds, implying that more productive firms are more likely to enter international markets in the first place (Melitz 2003). Building on this selection margin, international transactions are further shaped by matching and contractual frictions rooted in imperfect information and relationship-specific investments, which manifest as elevated search costs, bargaining costs, and contract-enforcement costs (Rauch 1999, Rauch & Watson 2003, Nunn 2007, Antràs & Chor 2013, Chaney 2014). As a result, even after conditioning on firm capabilities, whether a firm can form stable cross-border trade and supply-chain linkages depends critically on the extent to which its trading networks can mitigate these frictions (Rauch 1999, Rauch & Watson 2003, Chaney 2014).

In cross-border supply chains where environmental performance is difficult to observe and enforce, baseline compliance requirements and third-party certification can function as institutionalized devices for mitigating information and enforcement frictions (Nakamura et al. 2001). To earn buyer trust, firms often have to meet minimum environmental compliance benchmarks and convey credible baseline capability through auditable management systems such as ISO 14001, which function as a signal of process governance and compliance capacity (Nishitani 2010). Existing evidence shows that downstream customer pressure and compliance communication can induce suppliers to adopt these standardized and verifiable environmental management practices, and that such "entry-type" requirements are particularly prevalent when firms sell into markets with stronger environmental preferences or more stringent regulatory environments (Nakamura et al. 2001, Delmas & Montiel 2009, Nishitani 2010). Accordingly, at early stages of internationalization, foreign engagement is more likely to operate by pushing firms to a "green threshold", moving from no formal system to basic environmental management and compliance, rather than immediately triggering high-cost, relationship-specific process and technology upgrading.

In contrast, intensive green upgrading is more likely to arise when internationalization takes the form of integration into GVCs. In such settings, lead firms translate environmental objectives into supply-chain governance through standard setting, codifiable requirements, and coordinated production, and they reinforce these requirements via ongoing performance assessments, process audits, and documentation and disclosure mandates, thereby turning external environmental pressures into persistent constraints on suppliers' internal capabilities (Gereffi et al. 2005, Nishitani 2010). As a result, green transformation is often institutionalized as executable and verifiable tasks of process control and production upgrading rather than as a one-off compliance statement or a threshold certification (De Marchi et al. 2013, Ponte 2022). Taken together, this implies that the mode of internationalization could determine whether firms remain at the level of threshold compliance or are pushed onto a trajectory of intensive upgrading that requires sustained investment.

Importantly, green transformation is multidimensional. A useful distinction is between product-oriented greening and process-oriented greening (OECD 2008). The product-side is closer to demand-driven attribute upgrading in international markets, where firms adjust product characteristics and pricing in response to market access and buyer requirements (Verhoogen 2008, Kugler & Verhoogen 2012, Fontagné et al. 2015). In contrast, process-side greening often entails lumpy, fixed-cost, investments in abatement and management. Stronger international engagement can raise the return to such investments through economies of scale that lowers emissions intensity among exporters (Forslid et al. 2018). Moreover, because process performance is relatively simple to measure and verify, it can be more easily monitored, tilting firms toward sustained process upgrading rather than one-off product adjustments (Humphrey & Schmitz 2002, Giuliani et al. 2005). Accordingly, the destination and mode of internationalization shapes not only whether firms move beyond threshold compliance, but also whether green transformation is concentrated on products or production processes.

For Japanese manufacturing firms, Asia's mature but fragmented production network, supported by dense industrial clusters and well-developed markets, lowers the coordination costs and uncertainty of cross-border production sharing, making it easier to enter regional production networks and form stable intermediate-input trade relationships (Kimura & Ando 2005, Obashi 2010, Baldwin 2013). In this sense, Asia-centered links are most likely to expand international participation on the extensive margin, without necessarily inducing immediate, high-intensity organizational or technological restructuring.

In contrast, many Western markets, particularly the European Union (EU), translate environmental requirements into verifiable product and process standards and transmit compliance responsibilities upstream through regulation and supply-chain due diligence (Gereffi et al. 2005). Policies such as the Restriction of Hazardous Substances (RoHS), the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH), and and more recently the Carbon Border Adjustment Mechanism (CBAM), together with due-diligence regimes, increase the data, reporting, and auditing demands faced by suppliers (EU 2011, 2006, 2023, 2024). Consistent with evidence that auditable environmental management practices (e.g., ISO 14001) diffuse due to supply-chain pressures, especially when firms serve environmentally stringent markets (Nishitani 2010, Arimura et al. 2011), Western-oriented GVC integration is more likely to be associated with intensive, process-side upgrading rather than threshold compliance alone.

Building on this discussion, we derive three empirical hypotheses. First, green firms are more likely than non-green firms to internationalize, particularly through Asia-linked networks. Second, intensive greenness is expected to be concentrated among firms that are integrated into GVCs, especially those connected to Western-oriented supply-chain networks. Third, because process performance is more readily measurable and auditable, the association with highly integrated, Western-oriented GVCs should be stronger for process-side than for product-side greening.

3 Data and Measurement

3.1 Data and sample

We use firm-level data from *the Firm Survey on Uncertainty and the Digital Economy* conducted by RIETI administered by Tokyo Shoko Research, Ltd.(TSR) between July and September 2025. The survey employed stratified random sampling targeting 12,000 Japanese manufacturing firms via online questionnaires, yielding 1,099 valid responses (a 9.1% response rate; see Okubo & Mikawa (2026), for details). This dataset is well-suited for our analysis as it combines basic firm characteristics such as sales, tangible capital assets, employment with detailed modules on green transformation (specifically engagement in green jobs) and internationalization. The data provide an initial snapshot of the greenness of Japanese firms in 2025 to provide a series of stylized facts but also allows us to show the correlations between the greenness of firms across different dimensions and their patterns of internationalization.

More specifically, the survey considers two dimensions of green activities: (i) the provision of green products and services, and (ii) the adoption of green production processes within the firm.[1] This dual nature of green activities motivates our choice of measurement units. For green products and services, the relevant outcome is the market value of the final output, so we use the *share of total sales* in each green category. For green production processes, the activities are internal to the firm and do not generate separate sales. A natural proxy for the intensity of green engagement is therefore the *share of employees* whose main work is devoted to green processes.[2] Therefore, the survey questionnaire is deliberately structured to capture these two dimensions separately.

On the product side, firms first assess whether each activity falls within the survey's definition of green products and services, and then report the corresponding sales share. Specifically, the questionnaire requests the approximate share of turnover accounted for by the following five product-side categories:

1. Recycling and greenhouse gas (GHG) emission reduction/pollution control;
2. Natural resource protection (e.g. organic agriculture, sustainable forestry, land, soil, water, and biodiversity protection);
3. Energy-efficiency related products (e.g. energy-efficient appliances, EVs, high-efficiency motors, LED lighting, insulation);
4. Products for energy generation or usage from renewable resources (e.g. solar panels, wind turbines, biomass fuels);
5. Compliance- and education-related environmental products and services (e.g. environmental education, compliance management systems).

On the production process side, green activities do not generate separate sales, but are reflected in how production is organized inside the firm. Accordingly, the questionnaire asks firms to report the *share of employees* (in percent) whose main work activities (more than half of their working time) are devoted to green production processes. Firms indicate the approximate proportion of their workforce engaged in four process-side categories:

[1] Our classification of green activities follows, with some small adjustments, the green jobs taxonomy developed by the U.S. Bureau of Labor Statistics (BLS) for measuring green jobs (see BLS (2012)).

[2] The survey design reflects the fact that green activities can arise in two distinct but potentially overlapping ways: (1) workers involved in the production of green products and services, and (2) workers engaged in greening the production process. A given firm may therefore simultaneously generate turnover from green products and employ workers whose main tasks are related to green production processes.

1. Recycling, reuse, GHG emission reduction, and pollution abatement within the firm;

2. Activities aimed at conserving natural resources (including environmentally conscious input use and resource management);

3. Activities to improve energy efficiency (e.g. energy-saving practices and related technology development);

4. Activities related to the generation and use of energy from renewable resources within the firm.

In addition, the survey measures multiple dimensions of international engagement beyond exporting, including imports, participation in global supply chains, technology transactions/collaboration, and foreign direct investment (FDI). Destination regions are reported using binary indicators for the EU, the US, Asia (excluding China), China, and other regions. Furthermore, the data captures exposure to external shocks, specifically asking about the impact of the April 2025 Trump tariff shock on sales, which serves as our primary proxy for trade-policy vulnerability.

3.2 Construction of Green Indices

3.2.1 Green Product Share

As outlined in the previous section, the questionnaire distinguishes between five product-side categories: (1) recycling/greenhouse gas (GHG) reduction, (2) natural resource protection, (3) energy-efficiency related products, (4) renewable-energy generation/usage products, and (5) compliance/education-related environmental products and services.

Conceptually, these five categories can be further grouped into three broader groups:

- Block A: Environmental protection (categories (1) + (2));
- Block B: Energy transition (categories (3) + (4));
- Block C: Regulatory/educational enabling services (category (5)).

To identify product-side greenness in manufacturing firms, we first use all five components and take the simple equal-weighted average across them in our baseline. Let p_i denote the percentage share of total sales for item $i \in \{1, \ldots, 5\}$. Hence, the overall green product share is defined as;

$$\text{Green Product Share} = \frac{1}{5}\sum_{i=1}^{5} p_i. \tag{1}$$

In addition, we construct block-level indices for the three groups introduced above. Let block A (environmental protection) comprise categories (i) and (ii), block B (energy transition) comprise categories (iii) and (iv), and block C (regulatory/educational enabling services) correspond to category (v). The associated green product shares are given by;

$$\begin{aligned}
\text{Green Product Share}^A &= \frac{1}{2}\big(p_1 + p_2\big), &(2)\\
\text{Green Product Share}^B &= \frac{1}{2}\big(p_3 + p_4\big), &(3)\\
\text{Green Product Share}^C &= p_5. &(4)
\end{aligned}$$

Because block C (compliance/education) is conceptually different from the two "real-output" blocks (A and B), we also construct a sub-index that excludes category (v) as a robustness check. Formally, this alternative index is the equal-weight average over the first four components given by;

$$\text{Green Product Share}^{\text{noC}} = \frac{1}{4}\sum_{i=1}^{4} p_i. \tag{5}$$

All indices are expressed in percentage points (0-100) of total sales and can be normalized (e.g. by dividing by 100) in the regression analysis.

3.2.2 Green Processes Share

On the process side, the questionnaire distinguishes four categories, which again map naturally into two blocks: Block A (environmental protection: recycling and resource protection) and Block B (energy transition: energy saving and renewable energy usage). Let e_j be the percent share of employees in process category $j \in \{1, \ldots, 4\}$. Similarly to the product indices, we define block-level indices for the two conceptual groups given by;

$$\begin{aligned}
\text{Green Process Share}^A &= \frac{1}{2}\big(e_1 + e_2\big), &(6)\\
\text{Green Process Share}^B &= \frac{1}{2}\big(e_3 + e_4\big), &(7)
\end{aligned}$$

where block A captures environmental protection activities (recycling and natural resource protection) and block B captures energy transition activities (energy saving and renewable energy usage).

Because workers may contribute to both process categories, the "true" green employee share lies between a lower bound and an upper bound where we define;

$$\begin{aligned}
\text{Lower Bound} &= \max_j e_j, &(8)\\
\text{Upper Bound} &= \min\left(\sum_{j=1}^{4} e_j,\ 100\right), &(9)
\end{aligned}$$

where the upper bound is truncated at 100 percent. Our preferred process measure is the midpoint of this interval:

$$\text{Green Process Share} = \frac{\text{Lower Bound} + \text{Upper Bound}}{2}. \tag{10}$$

Both measures are in percentage points (0-100) and can be normalized (e.g. by dividing by 100) in the regression analysis.

3.2.3 Green Dummy Variables

For the comparison of subpopulations, we also define green dummy variables based on the continuous indices above. A firm is coded as a *green product firm* if Green Product Share > 0, and coded as a *green process firm* if Green Process Share > 0. Combining the two dimensions yields four mutually exclusive groups: (i) non-green firms (neither dimension > 0), (ii) green product only, (iii) green process only, and (iv) both green (positive for green products and green processes).

4 Stylized facts

4.1 The greenness of Japanese manufacturing firms

We begin by documenting the distribution of green firms in our sample and how the green share differs across firm types. Using the two dimensional definition introduced above, Table 1 reports the distribution of these groups in the sample, together with the average Green Product Share and Green Process Share in each group.

Table 1: Distribution of green firm types and average green shares (2025)

	Number of firms	Share of sample (%)	Green Product Share (mean, p.p.)	Green Process Share (mean, p.p.)
Green both	233	21.2	9.6	35.2
Green product only	84	7.6	8.5	0
Green process only	227	20.7	0	33.3
Non-green	555	50.5	0	0
Total	1,099	100.0	2.7	14.3

Notes: This table reports the distribution of firms according to the two-dimensional definition of green firms based on green products and green production processes in 2025. Green Product Share and Green Process Share are defined in Section 3.2 and expressed in percentage points (0-100). By construction, non-green firms have zero values in both indices while green product only firms have zero values in Green Process Share and green process only firms have zero values in Green Product Share.

Table 1 summarizes the distribution of green firms in the sample and reports the average green shares for each firm type. Out of 1,099 firms, around half (50.5%) are classified as non-green. The remaining 49.5% are green in at least one dimension: 21.2% of firms are green both in products and processes, 7.6% are green only on the product side, and 20.7% are green only on the process side.

In the full sample, the average Green Product Share is about 2.7%, reflecting the fact that a large proportion of firms report no or only small green product sales. Green Process Share is on average higher than the product-side measure (14.3%).[3] Among green

[3]Taken together, the two measures imply an average overall green share of roughly 8.5% for manufacturing firms. The magnitude is comparable to the level documented in the work of Kuai et al. (2025) using Japanese worker-level information on green tasks. Applying a conceptually similar definition, Kuai

firms, those that are green in both dimensions exhibit the highest intensity of green activities, with an average green product share of about 9.6% and an average green process share of 35.2%. Firms that are green only on the product side have 8.5% of sales in green products while on the process side they are shown to have 33.3% of employees involved in green processes in some way.

Next we describe the distribution of the continuous green share indices introduced in Section 3.2. Figure 1 shows histograms for the overall product- and process-side measures, both for the full sample and conditional on being green in the respective dimension. Panels A and C show that the distributions are highly skewed towards zero, confirming that in both cases, a large majority of firms report no green products or processes, and only a minority exhibit positive green shares. Conditional on being green (Panels B and D), the majority of firms report relatively small positive values. For green products, the mass of the distribution is concentrated at lower shares of sales (below 8%), with the highest bars in both the lowest bins and the top-coded value of 20 percentage points. For green processes, positive shares are more widely dispersed, but they still remain heavily concentrated in the lower part of the 0-100 range, mostly around 20 percentage points, with a long upper tail reflecting a small group of firms in which a large fraction of employees are engaged in green production process activities.

Figure 2 decomposes these patterns by the block-level indices introduced in Section 3.2. On the product side, the environmental-protection component (product A) and the energy-transition component (product B) both display right-skewed distributions, with most firms reporting moderate shares and only a few firms reaching values above 30-40% of sales. The compliance/education component (product C) is also skewed towards low values, though a subset of firms exhibits relatively large shares in this category. The composite index that excludes block C (Product D) essentially mirrors the distribution of the main green product measure, confirming that our distribution are not driven solely by compliance- or education-related activities.

The process-side block indices in the lower panels of Figure 2 show a similar picture. Both the environmental-protection processes (process A) and the energy transition processes (process B) are characterized by a mass of firms with small green employee shares and a long but thin upper tail. Overall, these distributions suggest that while green activities are present in a sizable subset of firms (half of our sample), they typically account for only a limited share of output and employment, with intensive green engagement concentrated in a relatively small group of firms.

Figures 3 and 4 summarize how the distribution of green firms and intensity of green activities vary across manufacturing industries in our sample. Figure 3 shows, for each manufacturing industry, the within-industry distribution of firm types based on our two-dimensional definition (non-green, green product only, green process only, and green both). In all industries, non-green firms still account for a sizable share of establishments, typically close to one half of the industry, but there is marked heterogeneity in the composition of green firms. Rubber and plastics, general-purpose machinery, chemicals and petroleum, electrical equipment, and non-metallic minerals have a comparatively high proportion of firms that are green in both dimensions and/or on the process

et al. (2025) find that the average greenness of manufacturing is approximately 0.09 (9%).

Figure 1: Distribution of green product and process shares

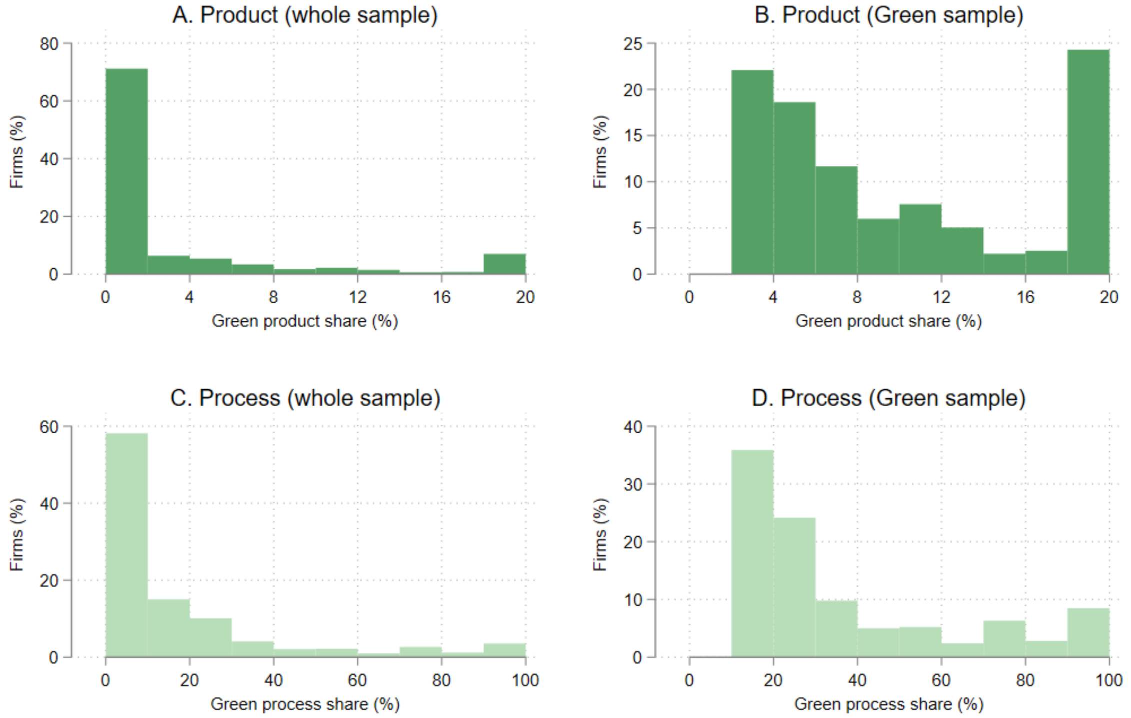
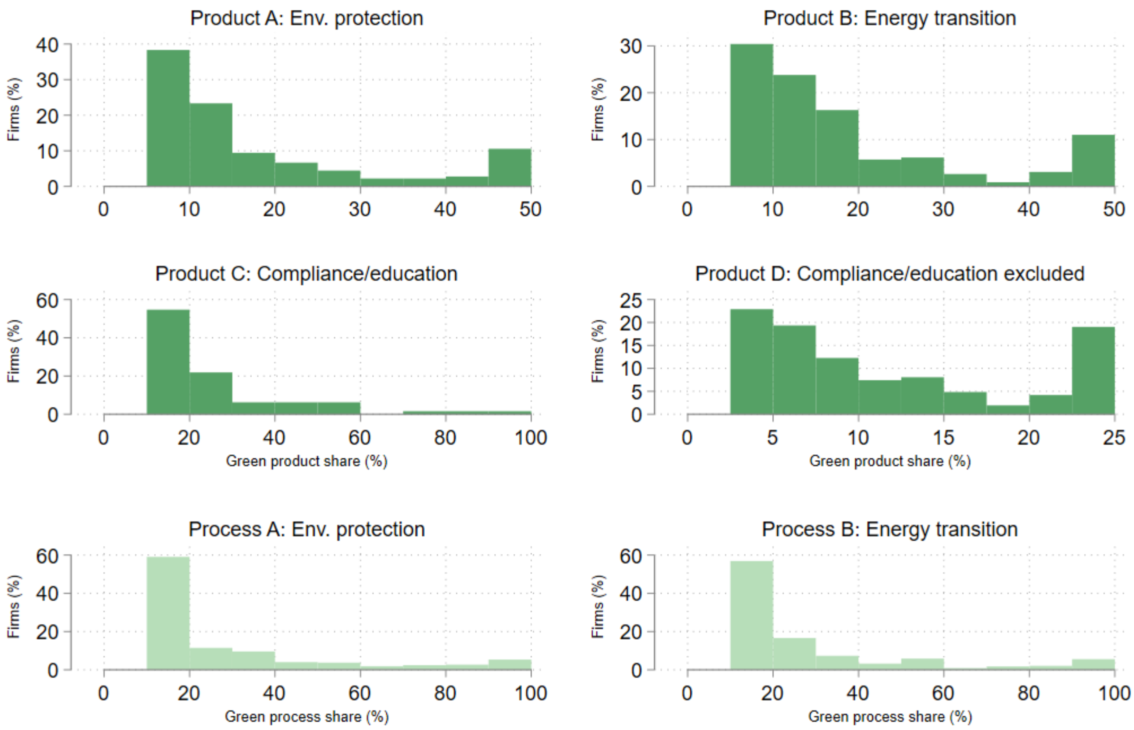


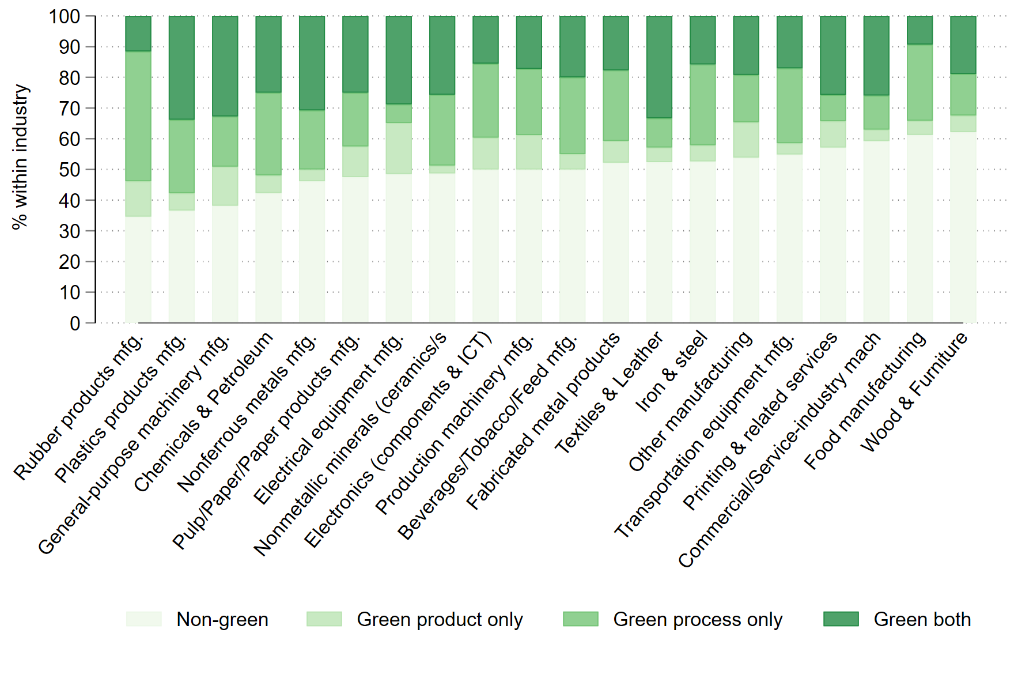
Figure 2: Distribution of green shares by block (Green sample)



side, suggesting a wider diffusion of green production technologies in these energy- and material-intensive manufacturing industries. By contrast, manufacturing branches such as food, wood and furniture, commercial and service-industry machinery and printing and related activities display a larger proportion of non-green firms and relatively few firms that are green across both dimensions.

Figure 4 reports, for the same set of manufacturing industries, the average Green Product Share and Green Process Share. In every industry the average green process share exceeds the average green product share, indicating that manufacturing firms are more likely to green their internal production processes than to produce green products. The cross-industry ranking broadly mirrors the patterns in Figure 3: nonferrous metals, plastics, pulp and paper, non-metallic minerals and beverages/tobacco exhibit the highest average green process shares, whereas electronics, fabricated metal products and food manufacturing show relatively low green process shares and small green product shares. Overall, the two figures suggest that green engagement within manufacturing is both more process-focused than product-focused and concentrated in a subset of energy- and resource-intensive branches, while a substantial share of firms in many manufacturing industries remain entirely non-green.

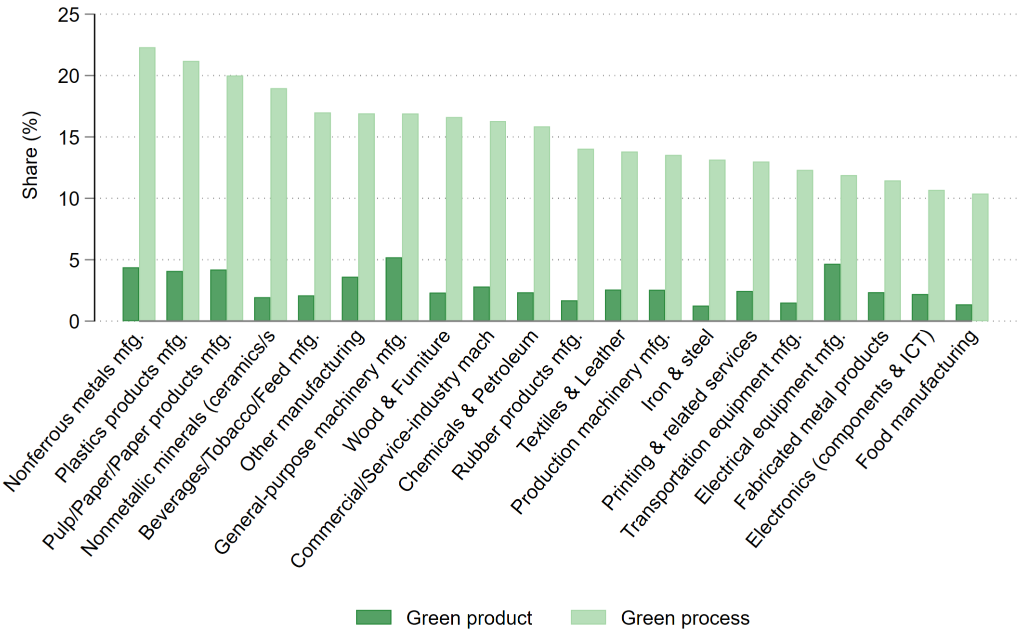
Figure 3: Distribution of green firms by industry



4.2 Green manufacturing and international engagement

The next stage of the analysis is to examine which types of green firms are more likely to engage in particular types of internationalization and to be connected to specific regions. Figure 5 reports industry-adjusted predicted probabilities of having international links by four mutually exclusive firm types. For each type of international engagement,

Figure 4: Average green product and process shares by industry



exports, imports, supply-chain linkages, and outward FDI, the figure shows the predicted probability of having at least one such link, conditional on the industry, with vertical bars indicating the confidence intervals.

The export panel in the upper left suggests a clear ordering across firm types. The predicted probability of exporting is around 0.45 for firms that are green for both products and processes, and of a similar magnitude for firms that are only green in products or only green in processes. By contrast, non-green firms in the 'other' group have a predicted export probability closer to 0.35. In other words, firms with any form of greenness are roughly 8-10 percentage points more likely to be exporters than firms that are not green along either dimension. The import panel in the upper right shows a similar, although somewhat less pronounced pattern. Firms that are product and process green have an import probability of just above 0.40, compared to roughly the mid-0.30s for the other three types. Thus, green-both firms are again several percentage points more likely to be importers than non-green firms.

The lower-left panel, which focuses on supply-chain linkages (defined as being connected to foreign firms through cross-border production relationships short of doing their own FDI), displays lower overall probabilities than exporting or importing but shows an even clearer gap between green and non-green firms. For green-both firms the industry-adjusted probability of having a foreign supply-chain link is around 0.22-0.23, and for green-product and green-process firms it is close to 0.20, whereas for non-green firms it is only about 0.12-0.13. This implies that green firms are on the order of 8-11 percentage points more likely to participate in international supply chains than firms without any green activities.

Finally, in the FDI panel on the lower right, predicted probabilities are lower than exporting and important and more tightly clustered. Green-both and green-product firms have FDI probabilities around 0.21-0.22, green-process firms around 0.20, and non-green firms around 0.16–0.17. The gap between green and non-green firms is therefore smaller for FDI than for exports, imports, or supply-chain link, on the order of 4-5 percentage points but the differences are not statistically significant.

Taken together, Figure 5 shows that, after adjusting for industry fixed effects, firms with green activities are systematically more likely to be internationally integrated than non-green firms. The association is strongest for export and supply-chain links, somewhat weaker for imports, and weakest for outward FDI. Moreover, firms that are green along both dimensions tend to have the highest probabilities of all four types of international links, while firms that are green only in products or only in processes lie in between the fully green and non-green groups. This pattern is consistent with the view that more comprehensive greening is intertwined with deeper participation in international markets and cross-border production networks.

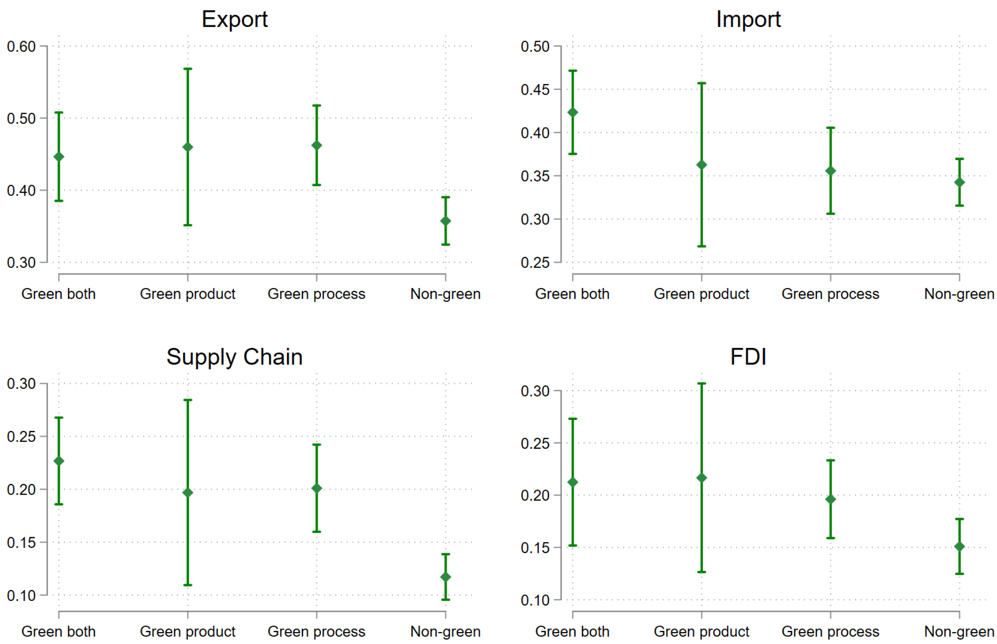
Finally, Figure 6 reports industry-adjusted predicted probabilities of having international engagement by destination market for the four mutually exclusive green firm types. For each international links, the figure plots separate probabilities for China, other Asian economies (excluding China), the US and the EU, together with confidence intervals. The export panel shows a clear ordering both across destinations and green types. For all four types, the probability of exporting to Asian markets (China or other Asia) is substantially higher than the probability of exporting to the US or the EU. Green-both firms, for example, have an export probability to China or other Asia on the order of 0.30-0.35, compared with roughly 0.20-0.25 for the US and the EU. A similar Asia-US/EU gap is visible for green-product and green-process firms, while non-green firms have the lowest export probabilities overall, especially when directed to the US and the EU. Thus, greener firms are more likely to be exporters in general, and this difference is particularly pronounced for exports to Asia.

The patterns for imports are broadly similar. Green-both and green-process firms exhibit the highest probabilities of importing from China and other Asian economies, typically in the range of 0.25-0.30, whereas their probabilities of importing from the US or the EU are closer to 0.10-0.15. Green-product firms also display relatively strong Asian import links, while non-green and green process firms have the lowest predicted import probabilities, in particular vis-à-vis the US. Taken together, the export and import panels suggest that green firms are more deeply integrated into intra-Asian trade networks than non-green firms, but their links to the US and EU markets are considerably weaker.

Destination-specific differences are also evident for international supply-chain engagement. Although the overall probabilities are lower than for exports and imports, green-both and green-process firms are noticeably more likely to be connected to Asian production networks than non-green firms. For these green firms, the probability of having China- or Asia-oriented supply-chain links is around 0.12-0.17, compared with roughly 0.05-0.10 for US- or EU- links. Non-green firms show very low probabilities of supply-chain links to any destination, and the Asia-US/EU gap is smaller. In contrast, outward FDI probabilities are relatively low and tightly clustered across green types and destinations. Green firms are somewhat more likely to have FDI into Asia than the US or EU, but the gaps are modest, in the order of a few percentage points, and non-green firms are only slightly less likely to have affiliates abroad.

Overall, Figure 6 indicates that the higher likelihood of international engagement among green firms documented above is driven primarily by a greater propensity to establish linkages within Asia. In other words, Asia-oriented trade and production networks appear to be driving where green firms are more likely to internationalize, whereas differences in engagement with the US and EU markets are comparatively modest, particularly for outward FDI.

Figure 5: Industry-adjusted predicted probabilities of international linkages by green firm types



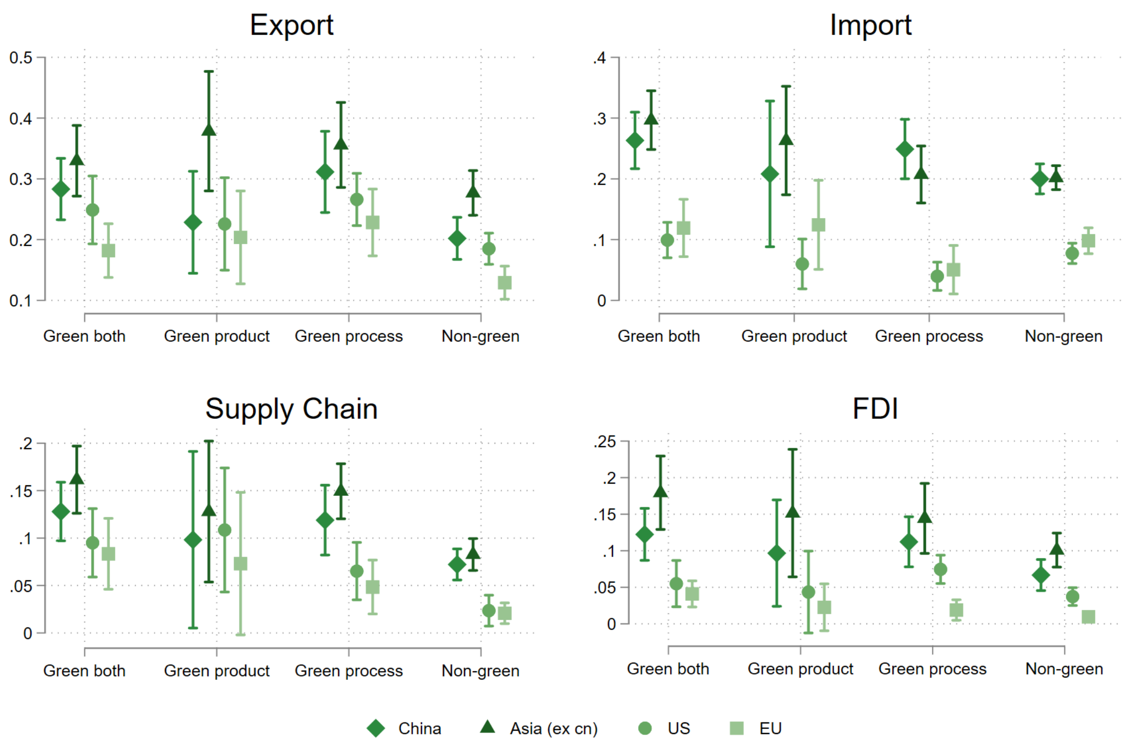
Note: This figure reports industry-adjusted predicted probabilities of having international linkages for four mutually exclusive firm types. For each type of linkage including exports, imports, supply-chain linkages, and outward FDI, the figure shows the predicted probability of having at least one such link, conditional on industry, with vertical bars indicating confidence intervals.

5 Empirical Specification

5.1 Baseline specification

To further examine whether firms' international engagement is systematically associated with their greenness, we estimate the following regression specification. Let $\text{GreenShare}_{ic}^{k}$ denote one of the continuous green share indices introduced in Section 3.2 for firm i in industry c and dimension k (total green product share or green product shares for blocks A, B and C, or total green process share or green process shares for

Figure 6: Industry-adjusted predicted probabilities of international engagement by destination and green firm type



Note: This figure reports industry-adjusted predicted probabilities of having international linkages by destination market for the four mutually exclusive green firm types. For each type of international linkage, the figure plots separate probabilities for China, other Asian economies (excluding China), the US and the EU, together with confidence intervals.

blocks A and B), all scaled to the unit interval. Our baseline specification relates green shares to a single indicator of international engagement and is given by;

$$\text{Green Share}_{ic}^{k} = \alpha^{k} + \beta^{k}\, any\_intl_{i} + \mathbf{X}_{i}'\boldsymbol{\gamma}^{k} + \mu_{c} + \varepsilon_{ic}^{k}, \tag{11}$$

where any_intl_i equals one if firm i engages in at least one type of international activity (exporting, importing, supply-chain integration/foreign partnering, or FDI), and zero otherwise. $\mathbf{X}_i$ includes firm controls: firm size (measured by ln(employees)), capital intensity (measured by $\ln(K/L)$), and profitability (measured by profit-to-sales ratio). μ_c denotes industry fixed effects.

5.2 International activity types

The binary indicator any_intl_i captures whether a firm is internationally active but does not distinguish between different modes of internationalization. This aggregation may mask heterogeneous relationships with greenness, if, for instance, arm's-length trade primarily affects market access and demand composition, while supply-chain integration facilitates technology transfer and managerial learning, and FDI reflects stronger commitment and potentially different selection.

To unpack such heterogeneity and provide a more informative interpretation, we decompose international engagement into mutually exclusive activity types. More specifically, we replace any_intl_i with mutually exclusive indicators capturing distinct international activity types given by;

$$\text{Green Share}_{ic}^{k} = \alpha^{k} + \beta_{1}^{k}\, trade\_only_{i} + \beta_{2}^{k}\, gvc_{i} + \beta_{3}^{k}\, fdi_{i} + \mathbf{X}_{i}'\boldsymbol{\gamma}^{k} + \mu_{c} + \varepsilon_{ic}^{k}. \tag{12}$$

where $trade\_only_i$ equals one for firms engaged in exporting and/or importing but not in GVCs and not undertaking FDI; gvc_i equals one for firms participating in GVCs (e.g., supply-chain integration/foreign partnering) but not undertaking FDI; and fdi_i equals one for firms undertaking FDI (regardless of other international activities). The omitted category is firms with no international activities.

5.3 GVC partner location

To examine heterogeneity within GVCs, we further differentiate GVC engaged firms by the location of their supply-chain partners, as partner location may proxy for differences in standards exposure, knowledge transfer, and technology diffusion.

We classify firms into mutually exclusive categories based on the geography of their supply-chain partners. *Asia only* captures firms whose supply-chain links are exclusively with Asian partners, while *Any West links* captures firms with at least one Western supply-chain partner (which may also include firms that simultaneously link to Asian partners or other regions). Firms without any reported supply-chain links serve as the reference group. We estimate the following specification given by;

$$\text{GreenShare}^k_{ic} = \alpha^k + \theta^k_1 \, Asia\ only_i + \theta^k_2 \, Any\ West\ links_i + \mathbf{X}'_i \boldsymbol{\gamma}^k + \mu_c + \varepsilon^k_{ic}, \tag{13}$$

In this specification, trade-only and FDI indicators are included additionally to isolate supply chain partner-geography variation. In addition, we keep the same firm controls and industry fixed effects as in the baseline models.

6 Main results

Table 2 reports average marginal effects (AMEs) from a fractional logit regression of firms' green shares on an indicator for international engagement, controlling for firm size, capital intensity, profitability, and industry fixed effects.[4] International engagement is positively associated with greener production and greener processes. Firms with any international activity have a 0.8 percentage point higher total green product share and a 3.1 percentage point higher total green process share.[5]

Across product blocks, international activity is associated with higher green shares in all three categories, although the magnitudes are modest: 1.1 percentage points for environmental protection products (AME = 0.011, $p < 0.05$), 0.8 percentage points for energy transition products (AME = 0.008, $p < 0.05$), and 0.5 percentage points for compliance/education-related products (AME = 0.005, $p < 0.10$). On the process side, the estimates are also positive in both blocks: 2.0 percentage points for environmental protection processes (AME = 0.020, $p < 0.10$) and 2.2 percentage points for energy transition processes (AME = 0.022, $p < 0.10$).

Turning to the controls, larger firms tend to have higher process-side green shares. ln(Emp) is strongly positively associated with the total green process share (AME = 0.020, $p < 0.01$) and with both process blocks, while its association with product-side greenness is weaker and statistically significant only for the energy transition product block (AME = 0.005, $p < 0.05$). Capital intensity, measured by $\ln(K/L)$, is also positively related to process-side greenness (AME = 0.013, $p < 0.05$). Profitability is not systematically related to green shares once firm controls and industry fixed effects are included.

Table 3 decomposes international engagement into three mutually exclusive modes: *Trade only*, *GVC* (without FDI), and *FDI* with firms that have no international activities serving as the omitted category. For reference, Appendix Table 2 reports the distribution of firms across the four international engagement types. All specifications include the same firm controls and industry fixed effects as in the baseline regressions, and standard errors are clustered at the industry level.

[4] As the dependent variables are fractional outcomes bounded between 0 and 1 (including possible boundary values), we estimate Eq. (11) - (13) using fractional logit models implemented as a generalized linear model (GLM) with a logit link. To facilitate interpretation, we report AMEs for the international activity indicators.

[5] To facilitate interpretation of the results, Appendix Table 1 reports summary statistics for the main variables.

The results indicate that the positive association in the baseline specification is driven primarily by supply-chain integration. Firms classified as *GVC* exhibit substantially higher green shares on both the product and process dimensions. The AME for the total green product share is 2.3 percentage points (AME = 0.023, $p < 0.01$), while the AME for the total green process share is 6.1 percentage points (AME = 0.061, $p < 0.01$). This pattern is also evident across subcategories: GVC participation is associated with higher green product shares in blocks A - C (AMEs of 0.024, 0.022, and 0.025; all significant at the 5 percent level) and higher green process shares in both process blocks (AME = 0.046 and 0.038; both significant at the 5 percent level).

In contrast, *Trade only* and *FDI* firms are not statistically distinguishable from non-international firms across outcomes. Point estimates for *Trade only* are positive but small and imprecisely estimated (e.g., AME = 0.004 for the total green product share and AME = 0.019 for the total green process share). Estimates for *FDI* are likewise small and statistically insignificant. Overall, Table 3 suggests that the baseline relationship between international engagement and greenness is concentrated among firms integrated into supply-chain networks, rather than among firms engaged in trade alone or FDI per se.

Table 4 refines the GVC analysis by distinguishing supply-chain linkages that are exclusively with Asian partners (*Asia only*) from linkages that involve at least one Western partner (*Any West link*), using firms without any reported supply-chain linkages as the reference group. All specifications include firm controls and industry fixed effects; trade-only and FDI indicators are additionally included as other international controls but are not reported. Standard errors are clustered at the industry level.

Two observations stand out. First, supply-chain links that involve Western partners are strongly and consistently associated with higher green shares. Relative to firms without supply-chain linkages, firms with *Any West link* have a 3.5 percentage point higher total green product share (AME = 0.035, $p < 0.01$) and a 8.1 percentage point higher total green process share (AME = 0.081, $p < 0.05$). The product-side associations are particularly pronounced for energy-transition and compliance/education-related products: the AMEs are 5.0 percentage points for the energy-transition product block (AME = 0.050, $p < 0.01$) and 8.2 percentage points for the compliance/education block (AME = 0.082, $p < 0.01$). On the process side, *Any West link* is also positively associated with both process blocks, with a 5.7 percentage point increase in environmental-protection processes (AME = 0.057, $p < 0.05$) and a positive but imprecisely estimated coefficient for energy-transition processes (AME = 0.046).

Second, the estimates for *Asia only* firms are small and generally not statistically distinguishable from zero, and in one case are negative. In particular, *Asia only* is associated with a lower green share in the energy-transition product block (AME = −0.015, $p < 0.05$), while effects on total product and total process shares are close to zero and statistically insignificant.

Taken together, the baseline positive association between international engagement and firm-level greenness conceals substantial heterogeneity across both the mode of internationalization and the structure of supply-chains. The evidence points to GVC participation as the main correlate with higher green shares. Moreover, within GVCs, the largest and most precisely estimated associations are concentrated among firms embedded in Western supply-chain networks, particularly on the process side and, within process, in environment-protection-related activities that are driving the result.[6]

[6] Using binary indicators of green engagement yields the same qualitative pattern: green engagement is not associated with internationalization per se, but is concentrated among firms embedded in GVCs, particularly in Western supply-chain networks, with stronger effects on the process side (Appendix Table 3).

Table 2: Average marginal effects of international activities on green share (2025)

	(1) Green Prod: total	(2) Green Prod A: env. protection	(3) Green Prod B: energy trans.	(4) Green Prod C: compl./educ.	(5) Green Proc: total	(6) Green Proc A: env. protection	(7) Green Proc B: energy trans.
Any_intl	0.008***	0.011**	0.008**	0.005*	0.031**	0.020*	0.022*
	(0.003)	(0.005)	(0.004)	(0.003)	(0.013)	(0.010)	(0.012)
ln(Emp)	0.002	0.001	0.005**	-0.003	0.020***	0.010*	0.019***
	(0.001)	(0.003)	(0.002)	(0.002)	(0.007)	(0.005)	(0.004)
ln(K/L)	0.000	0.001	-0.000	0.000	0.013**	0.009*	0.011*
	(0.002)	(0.002)	(0.005)	(0.002)	(0.006)	(0.005)	(0.007)
Profitability	-0.002	-0.001	-0.002	-0.001	-0.001	-0.000	-0.004
	(0.002)	(0.002)	(0.004)	(0.001)	(0.001)	(0.000)	(0.004)
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	942	942	942	942	942	942	942

Note: The table reports average marginal effects from fractional logit regressions of green shares on any international activity, controlling for industry fixed effects in 2025. Any international activity (*Any_intl*) is a binary indicator equal to one if the firm engages in at least one type of international activity, including exporting, importing, participating in supply chains, undertaking foreign direct investment, or having foreign business partners, and zero otherwise. Control variables include firm size (measured as ln(employees)), capital intensity ($\ln(K/L)$), and profitability (profit-to-sales ratio). Columns (1)-(4) refer to product-side green shares; columns (5)-(7) refer to process-side green shares. Standard errors in parentheses are clustered at the industry level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Average marginal effects of different types of international activities on green share (2025)

	(1) Green Prod: total	(2) Green Prod A: env. protection	(3) Green Prod B: energy trans.	(4) Green Prod C: compl./educ.	(5) Green Proc: total	(6) Green Proc A: env. protection	(7) Green Proc B: energy trans.
Trade only	0.004	0.007	0.002	0.001	0.019	0.017	0.009
	(0.004)	(0.007)	(0.004)	(0.006)	(0.017)	(0.014)	(0.014)
GVC	0.023***	0.024**	0.022**	0.025**	0.061***	0.046**	0.038**
	(0.007)	(0.010)	(0.010)	(0.010)	(0.021)	(0.018)	(0.016)
FDI	0.004	0.008	0.004	-0.003	0.028	0.006	0.030
	(0.004)	(0.008)	(0.007)	(0.003)	(0.023)	(0.015)	(0.022)
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	942	942	942	942	942	942	942

Note: The table reports average marginal effects from fractional logit regressions of green shares on mutually exclusive types of international activities in 2025. "Trade only" equals one for firms engaged in exporting and/or importing but not in GVC participation and not undertaking FDI; "GVC" equals one for firms participating in GVCs (e.g., supply-chain integration/foreign partnering) but not undertaking FDI; and "FDI" equals one for firms undertaking foreign direct investment (regardless of other international activities). The omitted category is firms with no international activities. All specifications control for firm size, capital intensity, profitability and industry fixed effects. Columns (1)-(4) refer to product-side green shares; columns (5)-(7) refer to process-side green shares. Standard errors in parentheses are clustered at the industry level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Average marginal effects of GVC partner location on green share (2025)

	(1) Green Prod: total	(2) Green Prod A: env. protection	(3) Green Prod B: energy trans.	(4) Green Prod C: compl./educ.	(5) Green Proc: total	(6) Green Proc A: env. protection	(7) Green Proc B: energy trans.
Asia only	-0.004	0.007	-0.015**	-0.001	0.017	-0.008	0.022
	(0.005)	(0.008)	(0.007)	(0.004)	(0.026)	(0.020)	(0.019)
Any West link	0.035***	0.004	0.050***	0.082***	0.081**	0.057**	0.046
	(0.010)	(0.013)	(0.012)	(0.026)	(0.037)	(0.027)	(0.028)
Other intl. controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	942	942	942	942	942	942	942

Note: The table reports average marginal effects from fractional logit regressions of green shares on GVC partner location indicators in 2025. The omitted category is firms without any supply-chain linkages. "Asia only" indicates firms whose supply-chain connections are exclusively with Asian partners. "Any West links" indicates firms with at least one supply-chain connection to a Western partner; this category may also include firms that simultaneously connect to Asian partners or other regions. All specifications include firm controls (firm size, capital intensity, and profitability) and industry fixed effects. In addition, trade-only and FDI indicators are included as other international controls but not reported in the table. Standard errors in parentheses are clustered at the industry level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

7 Further analysis

Having established that the association between international engagement and the greenness of a firm is mainly driven by supply-chains and particularly those linked to Western networks, we next examine whether greenness systematically shapes firms' exposure to trade policy shocks through international engagement.

On the one hand, greener firms may be better positioned to comply with foreign standards and maintain stable relationships with overseas partners, potentially mitigating adverse impacts. On the other hand, being greener may coincide with greater integration into international supply chains, increasing exposure to changes in trade barriers and policy uncertainty. We assess these competing channels by interacting international engagement with firm-level measures of green share.

To measure impact of recent trade policy shocks, we use the survey question on the impact of recent tariff increases on the firm sales. Responses fall into six categories: (1) substantially increased, (2) increased, (3) no change, (4) decreased, (5) substantially decreased, and (6) unknown. We define a binary outcome, $\textit{Negative Tariff Impact}_i$, equal to one if the firm reports that sales decreased (responses 4 or 5) and equal to zero if the firm reports non-negative effects (responses 1-3). We exclude "unknown" responses from the baseline definition.

We then estimate logit models of the following form given by;

$$\begin{aligned}\Pr(\textit{Negative Tariff Impact}_i = 1) = \Lambda\Big(&\alpha + \beta\, \textit{Intl\_Act}_i + \delta\, \textit{Green Share}_i^k \\ &+ \phi\, \textit{Intl\_Act}_i \times \textit{Green Share}_i^k + \mathbf{X}_i'\boldsymbol{\gamma} + \mu_c\Big).\end{aligned} \tag{14}$$

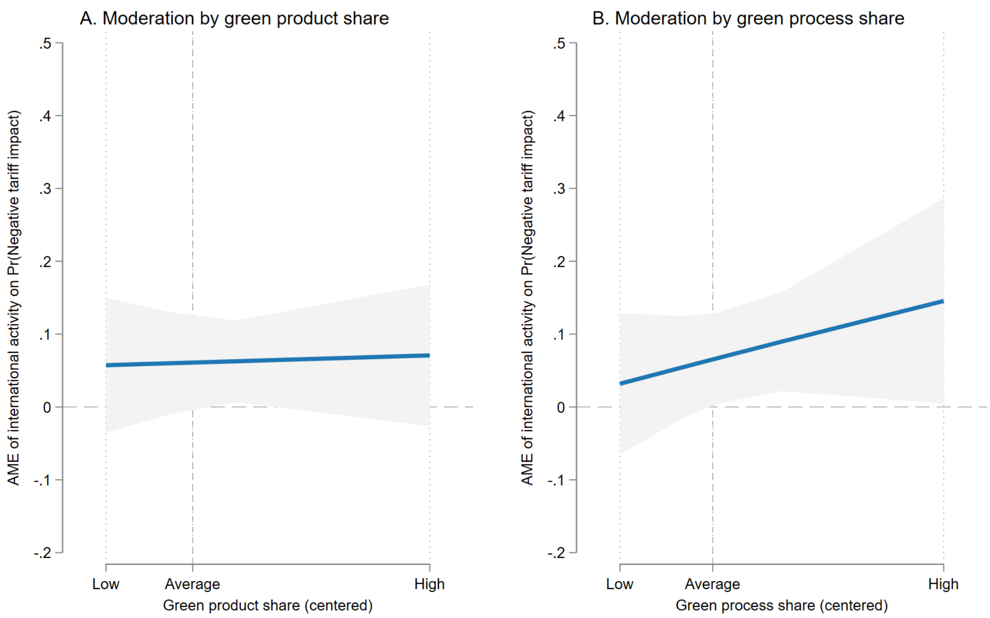
where $\mathbf{X}_i$ includes firm size, capital intensity, and profitability, and μ_c denotes industry fixed effects. $\textit{Intl\_Act}_i$ is measured using one of the international engagement indicators defined above, i.e. the international engagement indicators introduced in Eqs. 11 and 12. $\textit{Green Share}_i^k$ denotes the firm-level greenness measure (either the green product share or the green process share). The interaction coefficient ϕ captures whether the relationship between international engagement and tariff-related sales losses varies systematically with the degree of green share.

Figure 7 plots average marginal effects (AMEs) of international activity (*any_intl*) on the probability of reporting a negative tariff impact, evaluated across the distribution of green share. Panel A varies the (centered) green product share, whereas Panel B varies the (centered) green process share; shaded areas denote 95% confidence intervals. For reference, Appendix Table 4 reports the corresponding AMEs of baseline and evaluated at low, average, and high levels of each green share measure.

Two patterns can be observed. First, the marginal effect of international activity is relatively flat across the distribution of green *product* shares (Panel A). The point estimates change little from low to high product-side greenness, and the confidence intervals overlap substantially across the range, suggesting limited moderation by product-side greenness. Second, the marginal effect increases noticeably with green *process* shares

(Panel B). Firms with higher process-side greenness exhibit a larger positive marginal effect of international activity on the probability of a negative tariff impact, indicating that internationally engaged firms become more exposed to tariff-related sales losses at higher levels of process greenness intensity. Overall, the figure suggests that the moderating role of greenness intensity, if present, operates primarily through process-side rather than product-side greenness.

Figure 7: Moderation by greenness: international activity and tariff impact



Note: The figure plots average marginal effects (AMEs) of international activity (*any_intl*) on the probability of reporting a negative tariff-induced sales impact, evaluated at different levels of green share. Panel A varies the (centered) green product share, and Panel B varies the (centered) green process share. Shaded areas indicate 95% confidence intervals. "Low" and "High" correspond to the 10th and 90th percentiles of the centered green share, respectively, and "Average" corresponds to the sample mean (zero after centering).

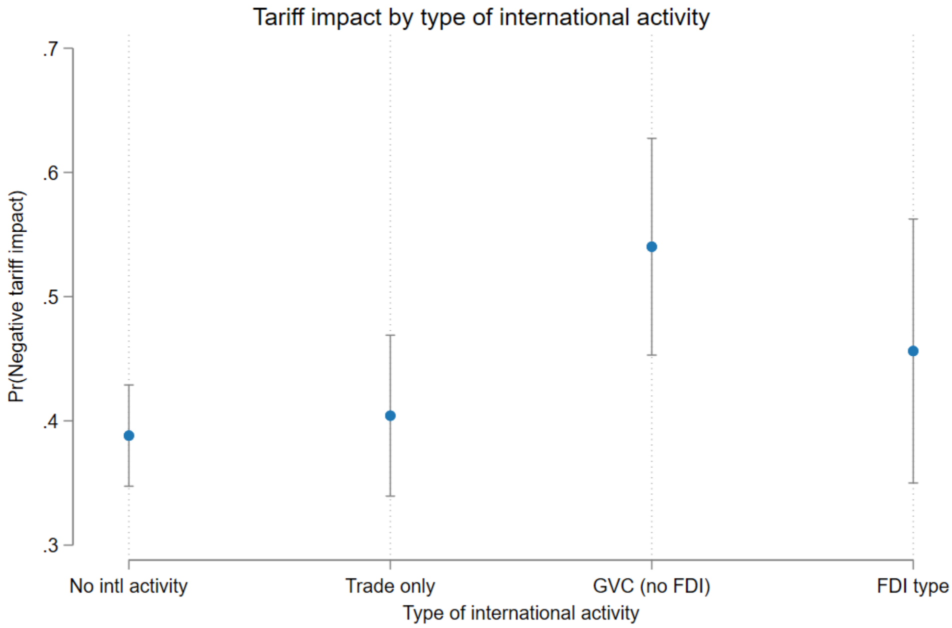
Figure 8 illustrates how exposure to tariff-induced sales losses varies systematically across modes of international engagement. More specifically, firms embedded in GVCs exhibit the highest predicted probability of negative tariff impacts relative to firms with no international activity. Given this observation, we next examine whether this gap is shaped by the degree of a firms' greenness. The full set of predictive margins by international activity type across green product and process intensity is reported in Appendix Figure 1.

Figure 9 contrasts predicted probabilities of reporting negative tariff impacts for firms with no international activity and for GVC firms (without FDI), evaluated at low, average, and high levels of greenness. First, the probability gap between GVC firms and non-international firms is substantial across the entire distribution of green shares, indicating that supply-chain integration is consistently associated with greater tariff exposure. Second, the gap is more sensitive to process-side greenness than to product-side greenness. In the process panel, predicted tariff exposure rises with green process intensity for GVC firms, while it declines with process intensity among firms with no international activity, widening the difference at higher levels of process greenness intensity. By contrast, the product panel shows comparatively little change across the distribution, suggesting limited heterogeneity with respect to product-side greenness intensity.

This contrast suggests that product-side greenness is more closely tied to product innovation and differentiation, which likely operates through demand-side channels and therefore need not translate into systematically higher tariff-related exposure. To the extent that differentiation buffers demand and supports markups when trade conditions deteriorate, the relatively flat pattern in the product panel is consistent with greater resilience of green product firms under negative trade-policy shocks. Process-side greenness, in contrast, often involves abatement-related investments and tighter operational integration within cross-border production networks; conditional on GVC engagement, such operational dependence may heighten firms' sensitivity to trade-policy shocks, contributing to higher reported tariff impacts.

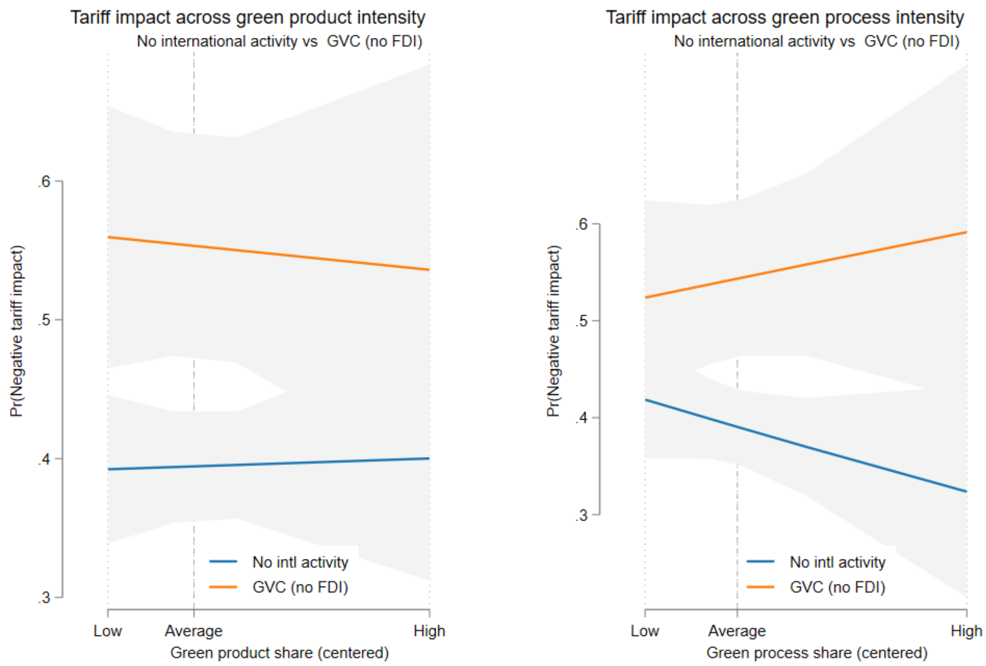
Taken together, these patterns are consistent with the view that process greenness is more tightly linked to the types of cross-border production relationships and operational dependencies that amplify exposure to trade-policy shocks, whereas product-side greenness appears less consequential for tariff-related sales impacts conditional on international engagement.

Figure 8: Tariff impact by type of international activity



Note: The figure plots predicted probabilities of reporting a negative tariff-induced sales impact across different types of international activity. Predicted probabilities are obtained from a logit model in which the dependent variable equals one if the firm reports that recent tariff increases reduced sales (responses 4 or 5), and zero otherwise. International activity types are defined as mutually exclusive categories: no international activity, trade only, GVC participation without FDI, and FDI-based engagement. All specifications control for firm size, capital intensity, profitability, and industry fixed effects. Vertical bars indicate 95% confidence intervals.

Figure 9: Moderation by greenness: No international activity vs GVC



Note: The figure plots predicted probabilities of reporting a negative tariff-induced sales impact for firms with no international activity and for firms embedded in GVCs without FDI. The left panel varies the (centered) green product share and the right panel varies the (centered) green process share. "Low" and "High" correspond to the 10th and 90th percentiles of the centered green share, respectively, and "Average" corresponds to the sample mean (zero after centering). Predictions are obtained from logit models that include firm controls (firm size, capital intensity, and profitability) and industry fixed effects. Shaded areas indicate 95% confidence intervals.

8 Conclusions

This paper leverages a new firm-level dataset covering Japanese manufacturing firms to examine the complex nexus between international engagement modes and firm-level greenness. Moving beyond binary measures of internationalization, we decompose greenness into "process-side" and "product-side" dimensions and unpack GVC engagement by different partner regions. This framework allows us to assess not only whether international engagement is associated with greenness, but also which types of cross-border links are most relevant. More importantly, we uncover a potential critical set of trade-offs between how green a firm is and economic security in the era of GVCs.

Our analysis yields three main findings. First, green engagement is widespread but uneven: it is predominantly process-oriented, typically limited in intensity, and exhibits pronounced heterogeneity across industries, with stronger intensity in energy- and material-intensive sectors. Second, international link matters but heterogeneously. while Asia-based trade networks largely explain the extensive margin of international participation, it is integration into Western GVCs, characterized by stricter environmental governance, that drives the intensive margin of substantive process greenness. Third, and most critically, this environmental compliance is not cost-free. We identify a latent "green vulnerability" mechanism whereby firms that are integrated into GVCs to meet rigorous environmental process standards systematically exhibit higher sensitivity to trade policy shocks. This suggests that in the current geopolitical landscape, the pursuit of environmental efficiency may inadvertently erode corporate resilience.

These findings have important implications for policymakers navigating the dual pressures of decarbonization and supply chain restructuring. Since GVC integration serves as a primary engine for substantive emissions reduction, a simple strategy of "decoupling" or retreating to lower-standard markets is suboptimal for climate goals. However, policymakers must also recognize that green technology transfers via GVCs often come bundled with heightened external dependency. Consequently, effective green industrial policy should not only incentivize the adoption of global environmental standards but may also be accompanied by complementary "resilience-enhancing" measures, such as early warning systems for trade shocks, support for export market diversification, and domestic safety nets to buffer green pioneers against external volatility.

Finally, we must acknowledge the limitations of this study, which point to important avenues for future research. The analysis is based on cross-sectional variation; while we include meaningful firm controls and industry fixed effects, the estimates should be interpreted as conditional associations rather than causal effects. In particular, selection may matter if more productive or better-managed firms both engage with Western-oriented GVCs and invest more in becoming greener. Future research using panel data and quasi-experimental variation in standards, buyer requirements, or trade-policy changes would help sharpen causal inference and trace the dynamics of upgrading under sustained policy uncertainty.

References

Antràs, P. & Chor, D. (2013), 'Organizing the global value chain', *Econometrica* **81**(6), 2127–2204.

Antweiler, W., Copeland, B. R. & Taylor, M. S. (2001), 'Is free trade good for the environment?', *American Economic Review* **91**(4), 877–908.

Arimura, T. H., Darnall, N. & Katayama, H. (2011), 'Is ISO 14001 a gateway to more advanced voluntary action? The case of green supply chain management', *Journal of Environmental Economics and Management* **61**(2), 170–182.

Baldwin, R. (2013), Global supply chains: Why they emerged, why they matter, and where they are going, *in* D. K. Elms & P. Low, eds, 'Global Value Chains in a Changing World', World Trade Organization, Geneva, pp. 13–59.

Banerjee, S. N., Roy, J. & Yasar, M. (2021), 'Exporting and pollution abatement expenditure: Evidence from firm-level data', *Journal of Environmental Economics and Management* **105**, 102403.

BLS (2012), 'Measuring green jobs', U.S. Bureau of Labor Statistics, Washington, DC. `https://www.bls.gov/green/`.

Chaney, T. (2014), 'The network structure of international trade', *American Economic Review* **104**(11), 3600–3634.

Cherniwchan, J., Copeland, B. R. & Taylor, M. S. (2017), 'Trade and the environment: New methods, measurements, and results', *Annual Review of Economics* **9**(1), 59–85.

Cole, M. A. & Elliott, R. J. (2003), 'Determining the trade–environment composition effect: the role of capital, labor and environmental regulations', *Journal of environmental economics and management* **46**(3), 363–383.

Cole, M. A., Elliott, R. J., Okubo, T. & Zhang, L. (2021), 'Importing, outsourcing and pollution offshoring', *Energy Economics* **103**, 105562.

Cole, M. A., Elliott, R. J., Okubo, T. & Zhou, Y. (2013), 'The carbon dioxide emissions of firms: A spatial analysis', *Journal of environmental economics and management* **65**(2), 290–309.

Copeland, B. R., Shapiro, J. S. & Taylor, M. S. (2022), Globalization and the environment, *in* G. Gopinath, E. Helpman & K. Rogoff, eds, 'Handbook of International Economics', Vol. 5, Elsevier, pp. 61–146.

Copeland, B. R. & Taylor, M. S. (2004), 'Trade, growth, and the environment', *Journal of Economic Literature* **42**(1), 7–71.

De Marchi, V., Di Maria, E. & Micelli, S. (2013), 'Environmental strategies, upgrading and competitive advantage in global value chains', *Business Strategy and the Environment* **22**(1), 62–72.

Dechezleprêtre, A. & Sato, M. (2017), 'The impacts of environmental regulations on competitiveness', *Review of Environmental Economics and Policy* **11**(2), 183–206.

Delmas, M. A. & Montiel, I. (2009), 'Greening the supply chain: When is customer pressure effective?', *Journal of Economics & Management Strategy* **18**(1), 171–201.

Eskeland, G. S. & Harrison, A. E. (2003), 'Moving to greener pastures? multinationals and the pollution haven hypothesis', *Journal of Development Economics* **70**(1), 1–23.

EU (2006), 'Regulation (ec) no 1907/2006 of the european parliament and of the council of 18 december 2006 concerning the registration, evaluation, authorisation and restriction of chemicals (reach), establishing a european chemicals agency, amending directive 1999/45/ec and repealing council regulation (eec) no 793/93 and commission regulation (ec) no 1488/94 as well as council directive 76/769/eec and commission directives 91/155/eec, 93/67/eec, 93/105/ec and 2000/21/ec'. Official Journal of the European Union, OJ L 396, 30.12.2006, pp. 1–849.
URL: *https://eur-lex.europa.eu/eli/reg/2006/1907/oj/eng*

EU (2011), 'Directive 2011/65/eu of the european parliament and of the council of 8 june 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast)'. Official Journal of the European Union, OJ L 174, 1.7.2011, pp. 88–110.
URL: *https://eur-lex.europa.eu/eli/dir/2011/65/oj/eng*

EU (2023), 'Regulation (eu) 2023/956 of the european parliament and of the council of 10 may 2023 establishing a carbon border adjustment mechanism'. Official Journal of the European Union, OJ L 130, 16.5.2023, pp. 52–104.
URL: *https://eur-lex.europa.eu/eli/reg/2023/956/oj/eng*

EU (2024), 'Directive (eu) 2024/1760 of the european parliament and of the council of 13 june 2024 on corporate sustainability due diligence and amending directive (eu) 2019/1937 and regulation (eu) 2023/2859'. Official Journal of the European Union, OJ L, 2024/1760, 5.7.2024.
URL: *https://eur-lex.europa.eu/eli/dir/2024/1760/oj/eng*

Fontagné, L., Orefice, G., Piermartini, R. & Rocha, N. (2015), 'Product standards and margins of trade: Firm-level evidence', *Journal of International Economics* **97**(1), 29–44.
URL: *https://doi.org/10.1016/j.jinteco.2015.04.008*

Forslid, R., Okubo, T. & Ulltveit-Moe, K. H. (2018), 'Why are firms that export cleaner? International trade, abatement and environmental emissions', *Journal of Environmental Economics and Management* **91**, 166–183.

Gereffi, G., Humphrey, J. & Sturgeon, T. (2005), 'The governance of global value chains', *Review of International Political Economy* **12**(1), 78–104.

Giuliani, E., Pietrobelli, C. & Rabellotti, R. (2005), 'Upgrading in global value chains: Lessons from latin american clusters', *World Development* **33**(4), 549–573.
URL: *https://doi.org/10.1016/j.worlddev.2005.01.002*

Grossman, G. M. & Krueger, A. B. (1991), Environmental impacts of a north american free trade agreement, NBER Working Paper 3914, National Bureau of Economic Research.
URL: *https://www.nber.org/papers/w3914*

Humphrey, J. & Schmitz, H. (2002), 'How does insertion in global value chains affect upgrading in industrial clusters?', *Regional Studies* **36**(9), 1017–1027.
URL: *https://doi.org/10.1080/0034340022000022198*

IDE-JETRO (2011), *Trade Patterns and Global Value Chains in East Asia: From Trade in Goods to Trade in Tasks*, World Trade Organization, Geneva.

IPCC (2022), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK and New York, NY, USA.
URL: *https://www.ipcc.ch/report/ar6/wg3/*

Kimura, F. & Ando, M. (2005), 'Two-dimensional fragmentation in East Asia: Conceptual framework and empirics', *International Review of Economics & Finance* **14**(3), 317–348.

Kuai, W., Elliott, R. J., Okubo, T. & Ozgen, C. (2025), Estimating the green wage premium, Technical report, IZA Discussion Papers.

Kugler, M. & Verhoogen, E. (2012), 'Prices, plant size, and product quality', *The Review of Economic Studies* **79**(1), 307–339.
URL: *https://doi.org/10.1093/restud/rdr021*

Levinson, A. & Taylor, M. S. (2008), 'Unmasking the pollution haven effect', *International Economic Review* **49**(1), 223–254.

Melitz, M. J. (2003), 'The impact of trade on intra-industry reallocations and aggregate industry productivity', *Econometrica* **71**(6), 1695–1725.

Meng, B., Xiao, H., Ye, J. & Li, S. (2019), Are global value chains truly global? A new perspective based on the measure of trade in value-added, IDE Discussion Paper 736, Institute of Developing Economies, Japan External Trade Organization (IDE-JETRO).

Nakamura, M., Takahashi, T. & Vertinsky, I. (2001), 'Why japanese firms choose to certify: A study of managerial responses to environmental issues', *Journal of Environmental Economics and Management* **42**(1), 23–52.

Nishitani, K. (2010), 'Demand for iso 14001 adoption in the global supply chain: An empirical analysis focusing on environmentally conscious markets', *Resource and Energy Economics* **32**(3), 395–407.

Nunn, N. (2007), 'Relationship-specificity, incomplete contracts, and the pattern of trade', *The Quarterly Journal of Economics* **122**(2), 569–600.

Obashi, A. (2010), 'Stability of production networks in East Asia: Duration and survival of trade', *Japan and the World Economy* **22**(1), 21–30.

OECD (2008), 'Sustainable manufacturing and eco-innovation: First steps in building a common analytical framework', *OECD, Paris* .

OECD (2023), ICIO-TiVA highlights: GVC indicators for Japan, Country note, Organisation for Economic Co-operation and Development.
URL: *hhttps://www.oecd.org/content/dam/oecd/en/topics/policy-sub-issues/trade-in-value-added/tiva-2023-JPN.pdf*

Okubo, T. & Mikawa, N. (2026), The main sources of uncertainty, their impacts and countermeasures of uncertainty in the japanese manufacturing firms: Overview of the firm survey on uncertainty and the digitalized economy, Rieti discussion paper, Research Institute of Economy, Trade and Industry (RIETI). Forthcoming, in Japanese.

Ponte, S. (2022), 'The hidden costs of environmental upgrading in global value chains', *Review of International Political Economy* **29**(3), 818–843. First published online 2020.

Rauch, J. E. (1999), 'Networks versus markets in international trade', *Journal of International Economics* **48**(1), 7–35.

Rauch, J. E. & Watson, J. (2003), 'Starting small in an unfamiliar environment', *International Journal of Industrial Organization* **21**(7), 1021–1042.

Richter, P. M. & Schiersch, A. (2017), 'CO2 emission intensity and exporting: Evidence from firm-level data', *European Economic Review* **98**, 373–391.

Rodrigue, J., Sheng, D. & Tan, Y. (2024), 'Exporting, abatement, and firm-level emissions: Evidence from China's accession to the WTO', *Review of Economics and Statistics* **106**(4), 1064–1082.

Verhoogen, E. A. (2008), 'Trade, quality upgrading, and wage inequality in the Mexican manufacturing sector', *The Quarterly Journal of Economics* **123**(2), 489–530.
URL: *https://doi.org/10.1162/qjec.2008.123.2.489*

Appendix

Table 1: Summary statistics

Variable	Obs	Mean	Std. dev.	Min	Max
Green Prod. total	1,099	0.027	0.056	0.000	0.200
Green Prod. A	1,099	0.026	0.082	0.000	0.500
Green Prod. B	1,099	0.035	0.094	0.000	0.500
Green Proc. total	1,099	0.012	0.067	0.000	1.000
Green Proc. A	1,099	0.090	0.191	0.000	1.000
Green Proc. B	1,099	0.081	0.181	0.000	1.000
Any_intl	1,099	0.571	0.495	0.000	1.000
ln(EMP)	1,067	4.807	0.870	2.565	10.600
ln(K/L)	959	2.066	1.181	-3.676	8.723
Profitbility	997	0.346	6.783	-7.154	194.182

Notes: This table reports summary statistics for the main variables used in the empirical analysis. The number of observations varies across variables due to missing values.

Table 2: Distribution of international engagement types

International engagement type	Freq.	Percent	Cum.
No intl activity	472	42.95	42.95
Trade only	295	26.84	69.79
GVC (no FDI)	136	12.37	82.17
FDI type	196	17.83	100.00
Total	1,099	100.00	

Notes: This table reports the sample distribution of firms across mutually exclusive international engagement types.

Table 3: Average marginal effects of international activities on green engagement dummy

	(1) Any green	(2) Green process	(3) Green product
Panel A: Any international activity			
Any_intl	0.070***	0.053**	0.031
	(0.023)	(0.025)	(0.027)
ln(Emp)	0.078***	0.073***	0.049***
	(0.019)	(0.023)	(0.017)
ln(K/L)	0.016**	0.027**	0.004
	(0.007)	(0.012)	(0.012)
Profitability	0.001	0.001	-0.018
	(0.002)	(0.002)	(0.018)
Panel B: Mode of internationalization			
Trade only	0.020	0.010	0.001
	(0.038)	(0.035)	(0.031)
GVC (no FDI)	0.188***	0.172***	0.112**
	(0.039)	(0.039)	(0.045)
FDI type	0.062	0.032	0.017
	(0.043)	(0.044)	(0.040)
Panel C: Destination of international linkages			
Asia only	0.038	0.050	-0.022
	(0.056)	(0.051)	(0.046)
Any West link	0.291***	0.207***	0.178***
	(0.050)	(0.065)	(0.059)
Observations	942	942	942

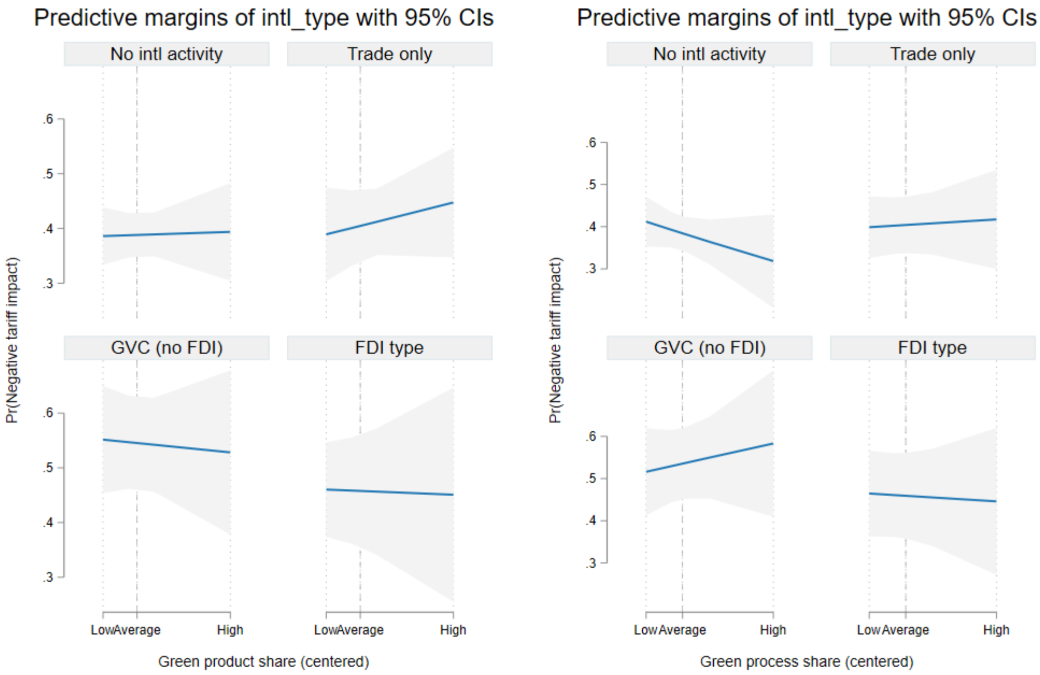
Notes: The table reports average marginal effects from logit regressions of green dummy outcomes on international activity indicators. The dependent variables are binary indicators constructed from firms' green activity type: *Any green engagement* equals 1 if the firm undertakes any green activity (green product only, green process only, or both), and 0 otherwise; *Green process* equals 1 if the firm undertakes green process activity (green process only or both), and 0 otherwise; *Green product* equals 1 if the firm undertakes green product activity (green product only or both), and 0 otherwise. All specifications include firm controls (firm size, capital intensity, and profitability) and industry fixed effects. Panel A reports the coefficients on the any-international-activity indicator and the firm controls. Panels B and C report the coefficients on the internationalization-type indicators; firm controls are included but not reported. In Panel B, the omitted category is no international activity. In Panel C, the specification additionally includes trade-only and FDI indicators as controls for other forms of international engagement (not reported); the omitted category is no international activity. Standard errors in parentheses are clustered at the industry level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Average marginal effects of international activity on negative tariff impacts at different levels of greenness

	(1) Baseline	(2) Prod: Low	(3) Prod: Avg	(4) Prod: High	(5) Proc: Low	(6) Proc: Avg	(7) Proc: High
Any international activity=1	0.062*	0.057	0.061*	0.071	0.032	0.065**	0.146**
	(0.033)	(0.047)	(0.033)	(0.050)	(0.049)	(0.032)	(0.072)
N	665	665	665	665	665	665	665
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports average marginal effects (AMEs) from logit models where the dependent variable equals one if the firm reports that recent tariff increases reduced sales (responses 4-5) and equals zero if the firm reports non-negative effects (responses 1-3). Column (1) reports the baseline AME of having any international activity. Columns (2)-(4) report the AME evaluated at low, average, and high levels of the (centered) green *product* share, and columns (5)-(7) report the AME evaluated at low, average, and high levels of the (centered) green *process* share. "Low" and "High" correspond to the 10th and 90th percentiles of the centered green share, respectively; "Avg" corresponds to the sample mean (zero after centering). All specifications include firm controls (log employment, capital intensity, and profitability) and industry fixed effects. Standard errors in parentheses are clustered at the industry level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. This table corresponds to Figure 7.

Figure 1: International activity type and tariff exposure across greenness intensity



Note: The figure plots predicted probabilities of reporting a negative tariff-induced sales impact across levels of greenness, separately by type of international activity. The dependent variable equals one if the firm reports that recent tariff increases reduced sales (responses 4 or 5) and equals zero if the firm reports non-negative effects (responses 1-3). The left block varies the (centered) green product share and the right block varies the (centered) green process share. Predictions are obtained from logit models that include firm controls (firm size, capital intensity, and profitability) and industry fixed effects. Shaded areas indicate 95% confidence intervals. "Low" and "High" correspond to the 10th and 90th percentiles of the centered green share, respectively; "Average" corresponds to the sample mean (zero after centering).