

Green Innovation and Export Performance of Manufacturing SMEs: The Mediating Role of Environmental Productivity

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Abstract

Small and medium-sized manufacturers are asked to cut their environmental footprint and, at the same time, to win customers abroad. This paper asks whether the two goals reinforce each other, and through which mechanism. We argue that green innovation raises a firm's *environmental productivity* (EP), the value it creates per unit of environmental pressure, and that higher EP in turn strengthens export performance by lowering cost, easing compliance with buyer and import requirements, supporting credibility in supply-chain audits, and improving quality. Drawing on the natural-resource-based view, the Porter hypothesis, and heterogeneous-firm trade theory, the paper develops six hypotheses: a path from green innovation to EP (H1), from EP to exports (H2), a direct path (H3), partial mediation through EP (H4), a stronger first path where absorptive capacity is high (H5), and a stronger second path in stringent destination markets (H6). We define EP formally, link it to a directional distance function, and set out a measurement and estimation design based on bootstrapped (moderated) mediation. Because no firm-level dataset is analysed, the empirical section is a *Monte Carlo illustration* of 420 simulated SMEs generated from assumed parameters; it shows how the model is estimated, interpreted, stress-tested with a 72-specification curve, and reported, and it must not be read as evidence about real firms. The illustration recovers an indirect effect of 0.139 (95% CI 0.094–0.190), about 55% of the total effect, and a conditional indirect effect that grows with absorptive capacity. The paper closes with managerial and policy implications and a research agenda for Bangladesh and other export-oriented emerging economies.

1. Introduction

Manufacturing SMEs sit at an awkward point in the global green transition. Buyers, retailers and import regulators increasingly ask suppliers to document energy use, chemical management and waste, while the same suppliers operate on thin margins, with limited technical staff and little access to long-term finance (Hillary, 2004; Love and Roper, 2015). For an export-oriented SME the question is therefore practical: does the money and effort spent on green innovation come back through the foreign market, or is it a pure compliance cost?

Two literatures speak to this question without meeting. The first studies whether being green pays. The Porter hypothesis argues that properly designed environmental pressure can trigger innovation offsets (?), and a long line of work in the resource-based tradition treats environmental capabilities as a source of advantage (??). Reviews find that the evidence is more favourable for weak versions of the hypothesis than for strong ones (Ambec et al., 2013), and firm-level studies relate green innovation to profitability with results that depend on the type of innovation (?Ghisetti and Rennings, 2014; ?). The second literature studies exporting. Exporters are more productive than non-exporters (Bernard and Jensen, 1999; Wagner, 2007), and trade theory explains why: only firms above a productivity threshold can pay the fixed cost of foreign markets (Melitz, 2003). Studies of export performance list product quality, innovation and market knowledge among its main correlates (?Sousa et al., 2008).

What is missing is a mechanism that is specific to the green side and that connects it to the productivity logic of trade. We propose *environmental productivity*, the value a firm generates per unit of environmental pressure, as that mechanism. EP is a productivity concept, so it fits the heterogeneous-firm account of who exports; it is also a green concept, so it is the quantity that green innovation is expected to move. The research questions are:

- RQ1** Does green innovation raise the environmental productivity of manufacturing SMEs?
- RQ2** Does environmental productivity raise export performance, and how much of the green-innovation effect on exports runs through it?
- RQ3** Which conditions (internal capability, destination-market re-

quirements) make the mediated pathway stronger?

- RQ4** How can the pathway be measured, estimated and reported credibly for SMEs?

The paper offers four contributions. It defines EP in a way that can be computed from data SMEs already hold; it builds a moderated-mediation model with six testable hypotheses; it provides a transparent estimation and robustness protocol; and it supplies a fully reproducible Monte Carlo illustration so that readers can see what each step produces. The literature drawn on is limited to publications up to 31 December 2022, and we are explicit that the illustration uses simulated data. Section 2 develops the theory, Section 3 the research design, Section 4 the simulation results, and Sections 5–7 the discussion, limitations and conclusion. Figure 1 previews the model.

2. Theory and Hypothesis Development

2.1 Three lenses

Three bodies of theory, summarised in Figure 2, motivate the model. The *natural-resource-based view* holds that capabilities in pollution prevention, product stewardship and sustainable development are valuable, rare and hard to imitate (?Barney, 1991); empirical work on small firms suggests that the resource logic carries over to SMEs (Aragón-Correa et al., 2008; ?), and that drivers of eco-innovation differ by innovation type in European SMEs (Triguero et al., 2013). The *Porter hypothesis* adds that regulatory or market pressure can stimulate innovation that partly or fully offsets compliance cost (?Lanoie et al., 2011). *Heterogeneous-firm trade theory* supplies the link to foreign markets: a firm exports only if its effective productivity clears a threshold set by the fixed and variable costs of entry (Melitz, 2003). Green innovation affects the third lens through the first two: if it raises EP, it raises the effective productivity that matters for crossing the export threshold.

2.2 Where the literature stands

Figure 3 places the main streams on a common time axis. Green innovation is usually split into product, process and organisational forms (Rennings, 2000; Dangelico and Pujari, 2010). Chen and co-authors report that green innovation performance is associated with firm advantage (Chen et al., 2006), and eco-innovation has been linked to pro-

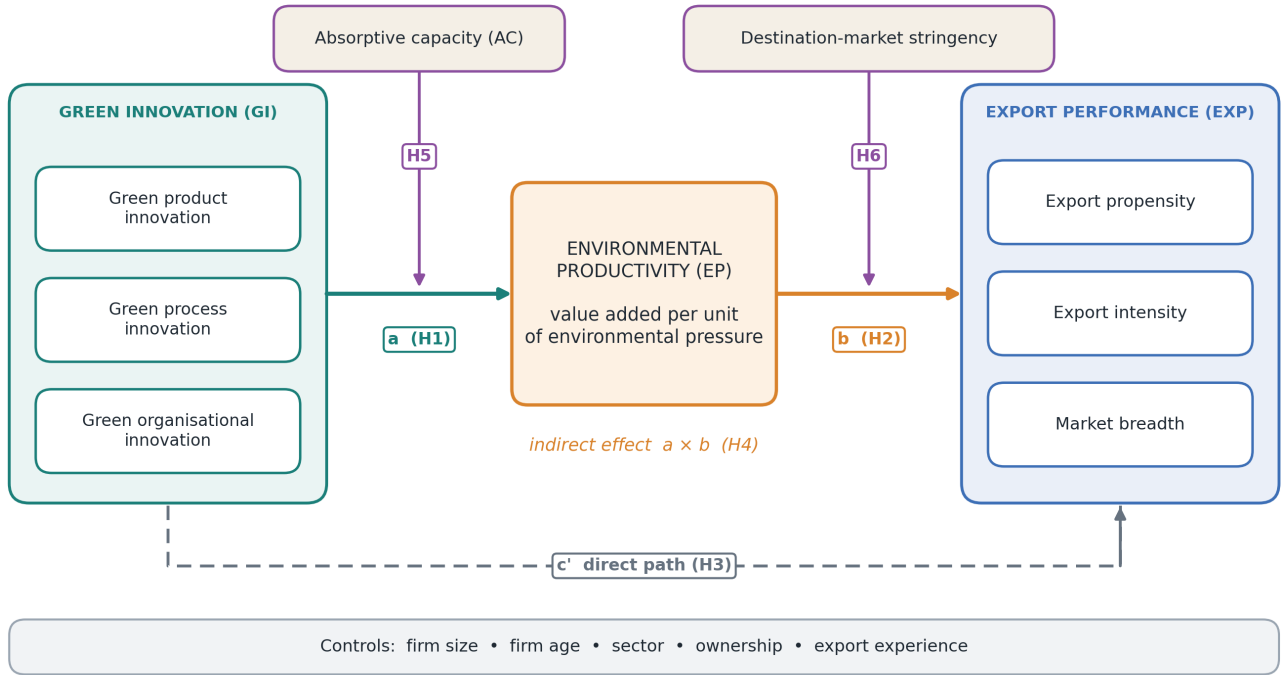


Figure 1. Conceptual model. Green innovation (three forms) raises environmental productivity (path a), which raises export performance (path b); a direct path c' remains. Absorptive capacity moderates a (H5) and destination-market stringency moderates b (H6).

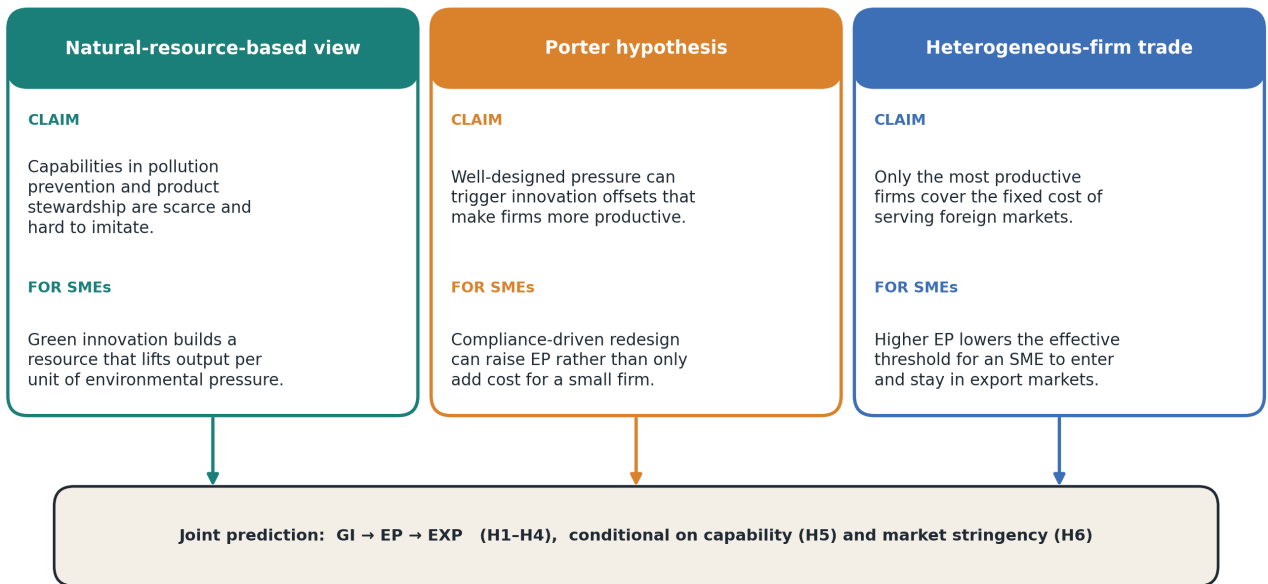


Figure 2. Three theoretical lenses and the joint prediction they support for manufacturing SMEs.

ductivity gains in firm data (?), and work on environmental technology distinguishes pollution prevention from end-of-pipe control, with prevention more closely tied to manufacturing performance (Klassen and Whybark, 1999). At the country level, Costantini and Mazzanti (2012) examine environmental policy and innovation in relation to the export competitiveness of EU countries and find little evidence that stringent policy undermines it. Reviews of SME innovation and exporting describe a two-way relationship in which innovation supports export entry and exporting in turn stimulates innovation (Love and Roper, 2015; ?). Absorptive capacity, the ability to recognise, assimilate and apply external knowledge (?), is the standard explanation of why firms differ in how much they gain from the same technology.

Two gaps follow. Few studies measure a green outcome in *productivity* units, so the green and trade literatures cannot be joined at the firm level; and mediation through such an outcome is rarely tested with methods suited to small samples. Table 1 sets out five gaps in the lit-

erature published up to the end of 2022 and the response taken in this paper.

2.3 Environmental productivity

Let firm i create value added y_i while generating a vector of environmental pressures $\mathbf{b}_i = (b_{i1}, \dots, b_{iJ})$, for example energy, water, and waste or emissions. A transparent index divides value added by a weighted pressure aggregate,

$$EP_i = \frac{y_i}{\sum_{j=1}^J \omega_j \tilde{b}_{ij}}, \quad \tilde{b}_{ij} = \frac{b_{ij}}{\bar{b}_j^{s(i)}}, \quad \sum_j \omega_j = 1, \quad (1)$$

where each pressure is scaled by its sector benchmark $\bar{b}_j^{s(i)}$ so that firms in different sectors are comparable. A frontier-based alternative treats value added as a good output and pressure as a bad output. With technology set T and a direction vector $\mathbf{g} = (g_y, -g_b)$, the directional dis-

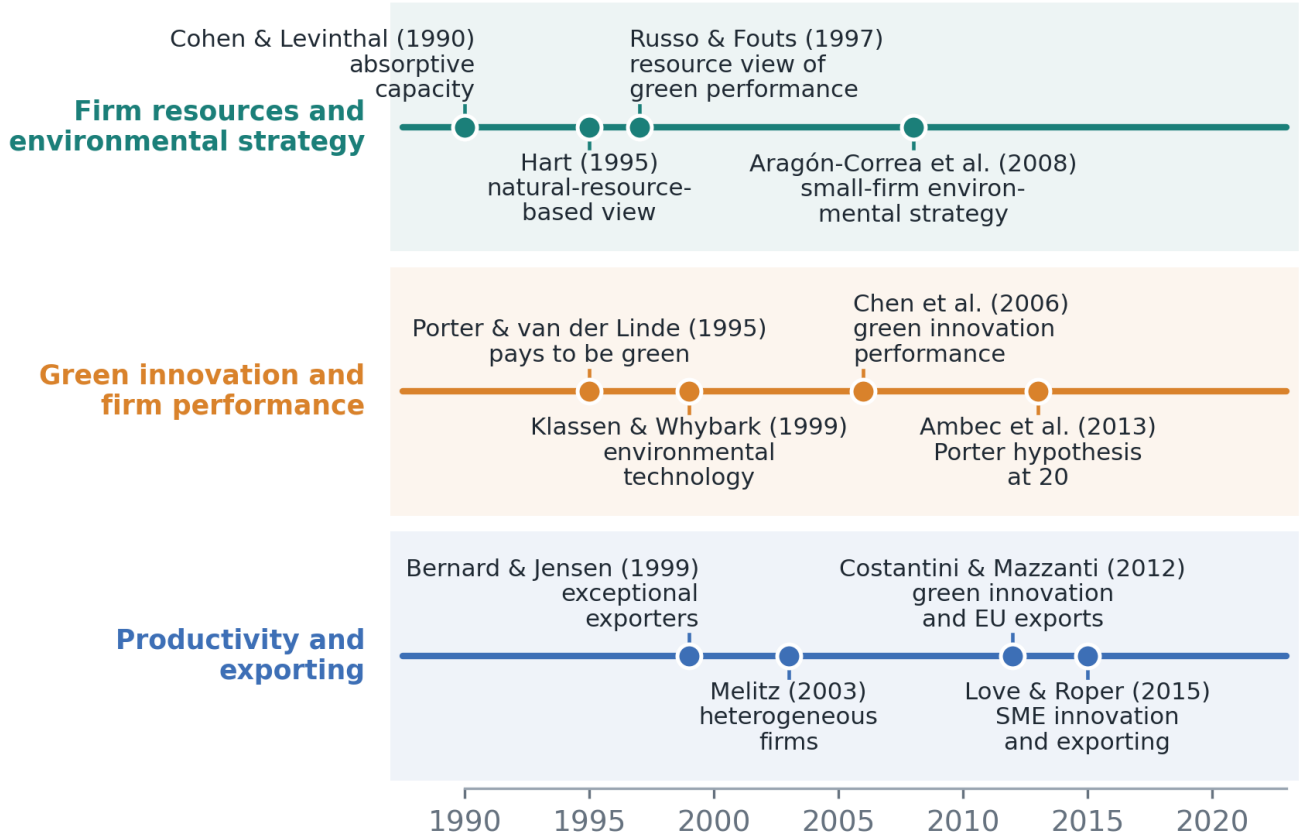


Figure 3. Scholarly lineage in three lanes: firm resources and environmental strategy, green innovation and firm performance, and productivity and exporting.

Table 1. Research gaps in the literature up to 2022 and how this study responds

#	Gap	What the cited work reports	Response in this paper
1	Outcome level: export results are rarely studied at the firm level	Firm studies relate green innovation to profitability or competitive advantage (Chen et al., 2006; ?; Ghisetti and Rennings, 2014; ?); the export link is examined at country–sector level (Costantini and Mazzanti, 2012)	Firm-level export composite of propensity, intensity and market breadth (H2, H3)
2	Mechanism: no common productivity measure joins the green and trade literatures	Eco-innovation is linked to productivity using patent and firm data (?), while trade models run on productivity thresholds (Melitz, 2003)	Environmental productivity defined from utility bills and accounts, with a frontier alternative (H1, H4)
3	Firm size: SME evidence concentrates on drivers and adoption	Drivers of eco-innovation and green strategy in small firms (Triguero et al., 2013; Aragón-Correa et al., 2008; ?); reviews of SME innovation and exporting (Love and Roper, 2015)	Population restricted to manufacturing SMEs with 10–249 employees
4	Conditions: capability and market requirements are seldom modelled together	Green absorptive capacity conditions green innovation (?); policy stringency and export competitiveness studied separately (Costantini and Mazzanti, 2012)	Moderated mediation by absorptive capacity (H5) and destination stringency (H6)
5	Inference: mediation tests rely on causal steps and single-source surveys	Causal-steps logic (Baron and Kenny, 1986) and common-method concerns (Podsakoff et al., 2003)	Bootstrap interval, records-based mediator and outcome, 72-specification curve (Simonsohn et al., 2020)

The table describes the direction of reported findings and does not pool effect sizes.

tance function

$$\tilde{D}(y, \mathbf{b}; \mathbf{g}) = \max\{\beta : (y + \beta g_y, \mathbf{b} - \beta g_b) \in T\} \quad (2)$$

measures the proportional room a firm has to expand value added and cut pressure simultaneously (??); related eco-efficiency work uses data-envelopment methods (Korhonen and Luptacik, 2004; Tone, 2001). Figure 4 shows both ideas. In panel (a) a firm below the frontier is projected onto it; in panel (b) EP rises along three routes: process innovation cuts pressure, product innovation raises value added, and combining them does both.

2.4 Hypotheses

Green innovation and EP (H1). Process innovation lowers material, energy and waste per unit of output; product innovation raises the value captured per unit of material; organisational innovation (environmental management routines) makes both durable. Each moves EP in Equation (1) in the same direction. **H1:** green innovation is positively associated with environmental productivity.

EP and exports (H2). Four channels connect EP to exports (Figure 5). *Cost:* lower resource use per unit lowers variable cost and

widens the margin available to cover export entry cost. *Compliance:* firms with lower pressure per unit meet buyer specifications and import rules at lower marginal cost. *Credibility:* documented performance helps pass supplier audits and retailer codes. *Quality:* cleaner, better-controlled processes tend to produce fewer defects and support differentiated products. If these effects raise effective productivity to $\tilde{\varphi}_i = \varphi_i EP_i^\lambda$ with $\lambda > 0$, the firm exports when $\tilde{\varphi}_i \geq \varphi_x^*$, and the export threshold is crossed at a lower baseline productivity φ_i . **H2:** environmental productivity is positively associated with export performance.

Direct and mediated effects (H3, H4). Green innovation may also help exports without any change in measured EP, for instance through eco-labels or brand signals. **H3:** green innovation has a positive direct association with export performance. **H4:** environmental productivity partially mediates the association between green innovation and export performance.

Moderators (H5, H6). Firms with higher absorptive capacity convert a given innovation effort into larger productivity gains (?), and green absorptive capacity has been shown to condition green innovation un-

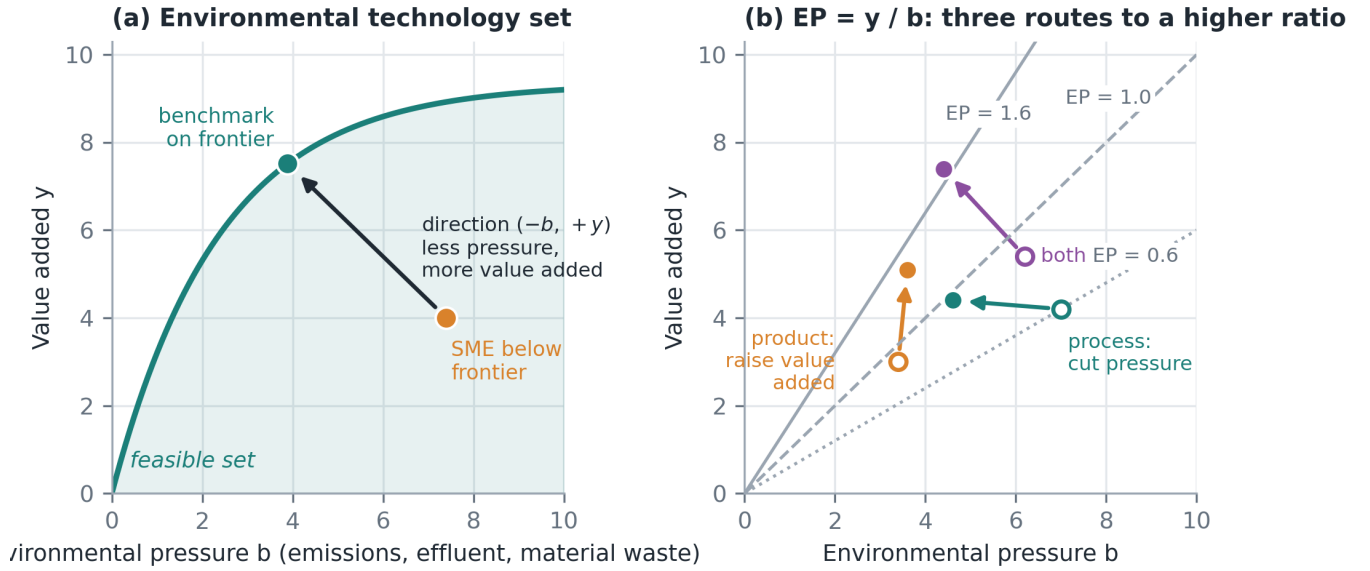


Figure 4. Environmental productivity. (a) Environmental technology set with an SME below the frontier and its projection along $(-b, +y)$. (b) Rays of constant EP and three innovation routes that raise it. Both panels are schematic.



Figure 5. Four channels from environmental productivity to three export outcomes. Bubble area is schematic and not estimated.

Table 2. Hypotheses, parameters and expected signs

No.	Statement	Parameter	Sign
H1	Green innovation raises environmental productivity	a (Eq. 3)	+
H2	Environmental productivity raises export performance	b (Eq. 4)	+
H3	Direct effect of green innovation on exports	c' (Eq. 4)	+
H4	Partial mediation through EP	$a \times b$ (Eq. 5)	+
H5	Absorptive capacity strengthens a ; moderated mediation	a_3 , index (Eq. 6)	+
H6	Market stringency strengthens b	b_2 (Eq. 7)	+

der regulatory pressure (?). Destination markets differ in the stringency of environmental requirements; the EP advantage should matter more where buyers and regulators demand more. **H5:** absorptive capacity strengthens the effect of green innovation on EP, so the indirect effect is larger at higher capacity (moderated mediation). **H6:** the effect of EP on export performance is stronger for firms selling mainly into high-stringency markets. Table 2 lists the hypotheses with their tests.

3. Research Design

3.1 Population, sampling and measures

The target population is manufacturing SMEs (10–249 employees) with some current or intended export activity, in sectors where environmental requirements from buyers are salient: garments and textiles, food processing, leather and footwear, plastics and light engineering, and chemicals and pharmaceuticals. For Bangladesh, a stratified sample from the establishment frame of the national statistics office, supplemented with exporter association lists, would be a natural starting point; access and consent must be confirmed before fieldwork. Table 3 defines the constructs. Survey items use seven-point scales; EP, exports and controls use records so that the mediator and outcome do not share a respondent-reported source where possible.

3.2 Estimation

Let all continuous variables be standardised. The moderated mediation model has a mediator equation and an outcome equation,

$$EP_i = a_0 + a_1 GI_i + a_2 AC_i + a_3 (GI_i \times AC_i) + \gamma_1' X_i + e_{1i}, \quad (3)$$

$$EXP_i = b_0 + c' GI_i + b_1 EP_i + \gamma_2' X_i + e_{2i}. \quad (4)$$

Table 3. Constructs, measures and sources

Construct	Operationalisation	Source
Green innovation (GI)	Mean of product, process and organisational sub-indices (3–5 items each: eco-design, cleaner production, material substitution, environmental management routines)	Owner/manager survey
Environmental productivity (EP)	Value added per sector-scaled pressure aggregate, Eq. (1); pressures: energy, water, solid waste	Utility bills; accounts
Export performance (EXP)	Composite of export propensity (any exports), intensity (export share of sales) and market breadth (number of destinations), standardised	Accounts; customs records
Absorptive capacity (AC)	Acquisition, assimilation and application of external knowledge (R&D staff share, training, technical partnerships)	Survey
Destination stringency (DMS)	Indicator: majority of export sales to markets with mandatory environmental import or buyer requirements	Customs; buyer lists
Controls	Employees (log), age, sector, ownership, export experience	Records

The effect of GI on EP at a given capacity level is $a(AC) = a_1 + a_3 AC$, so the conditional indirect effect and the index of moderated mediation (??) are

$$\theta(AC) = (a_1 + a_3 AC) b_1, \quad (5)$$

$$IMM = a_3 b_1. \quad (6)$$

At the mean of AC, $\theta = ab$. Hypothesis H6 is tested by adding DMS and $EP \times DMS$ to the outcome equation,

$$EXP_i = b_0 + c' GI_i + b_1 EP_i + b_2 (EP_i \times DMS_i) + b_3 DMS_i + \gamma_2' X_i + e_{2i}. \quad (7)$$

The total effect is $c = c' + ab$ and the share mediated is ab/c . Because the product ab is not normally distributed, inference relies on percentile bootstrap intervals (Preacher and Hayes, 2008) rather than the causal-steps logic of Baron and Kenny (1986). Self-selection into exporting is a concern in any observational application; a selection model (?), instruments for GI (for example exposure to subsidised green-technology programmes) and lagged specifications should be reported alongside the baseline. Common-method variance should be assessed where survey items appear on both sides (Podsakoff et al., 2003).

3.3 Simulation design

No field data are analysed. To show exactly how Equations (3)–(7) behave, we simulate $N = 420$ SMEs. Employees are log-normal and truncated to 10–249; the sector mix and destination split are shown in Figure 6. GI and AC are standard normal and mildly related to size; EP is generated from GI, AC, their product, controls and noise; exports are generated from GI, EP (with a slope that is larger for high-stringency firms), controls and noise. The assumed parameters are $a_1 = 0.45$, $a_3 = 0.15$, direct effect 0.12, and EP slopes of 0.28 (low-stringency) and 0.48 (high-stringency). EP is observed with measurement error. The seed and code are provided, so every number below can be reproduced. *These are illustrative values chosen by the authors, not estimates from firms.*

4. Simulation Results

Reading note. Everything in this section comes from simulated data generated with assumed parameters. The point is to show how the method works and what results would look like, not to claim that green innovation raises exports by any particular amount.

4.1 Descriptives and the basic association

Table 4 gives correlations among the main variables. Green innovation correlates 0.41 with EP, and EP correlates 0.40 with export performance, while the zero-order correlation between green innovation and exports is smaller (0.27), the pattern that a mediated structure predicts. Figure 7 shows the first path by capacity tercile: the fitted slope rises from 0.28 at low absorptive capacity to 0.56 at high capacity.

Table 4. Correlations among simulated variables ($N = 420$)

	GI	EP	EXP	AC
GI	1			
EP	0.41	1		
EXP	0.27	0.40	1	
AC	−0.03	0.20	0.07	1

Table 5. Estimates from the simulated data ($N = 420$, standardised variables, sector/size/age controls)

Quantity	Estimate	SE / 95% CI	Hypothesis
a : GI $\rightarrow$ EP (at mean AC)	0.427	SE 0.047	H1
b : EP $\rightarrow$ EXP	0.326	SE 0.047	H2
c' : direct, GI $\rightarrow$ EXP	0.113	SE 0.049	H3
c : total, GI $\rightarrow$ EXP	0.252	SE 0.048	–
$a \times b$: indirect effect	0.139	CI [0.094, 0.190]	H4
Share mediated	55.3%	–	H4
a_3 : GI $\times$ AC $\rightarrow$ EP	0.124	–	H5
Index of moderated mediation	0.041	CI [0.012, 0.074]	H5
R^2 : EP equation / EXP equation	0.226 / 0.285	–	–

4.2 Path estimates

Table 5 reports the main estimates from Equations (3)–(6) with sector, size and age controls. Green innovation raises EP ($a = 0.427$), EP raises exports ($b = 0.326$), and a smaller direct path remains ($c' = 0.113$), so the pattern is consistent with partial mediation (H1–H4). The indirect effect is 0.139, and the bootstrap interval in Figure 8 excludes zero. About 55% of the total effect of 0.252 passes through EP. The interaction a_3 is positive and the index of moderated mediation is 0.041 with an interval above zero (H5). The 95% intervals come from 5,000 resamples for ab and 3,000 for the index.

4.3 Heterogeneity across groups

Figure 9 reports the indirect effect within subgroups. It is positive in every group, with an interval that excludes zero in all of them, but the small sectors have wide intervals (for example leather and footwear, $n = 46$: estimate 0.206, CI [0.013, 0.380]), a reminder that subgroup estimates from SME samples are imprecise. The indirect effect is larger for high-stringency markets (0.168) than for low-stringency markets (0.114), in line with H6, although the intervals overlap, so the difference should not be over-interpreted from a single sample. Small firms show a slightly larger point estimate (0.148) than medium firms (0.114).

4.4 Moderated mediation

Figure 10 plots the conditional indirect effect $\theta(AC)$ over the range of absorptive capacity. At one standard deviation below the mean it is 0.095 (CI [0.050, 0.143]); at one standard deviation above it is 0.176 (CI [0.122, 0.240]). The interval excludes zero from roughly -1.7 SD upward, so the mediated route is detectable for most firms but is weakest where internal capability is lowest, which is the managerially relevant finding for SMEs.

4.5 Robustness: specification curve

Rather than report a single preferred model (Simonsohn et al., 2020), Figure 11 shows the indirect effect across 72 reasonable analytic choices: three EP measures (ratio index, noisier survey index, log-transformed ratio), four control sets, three estimators (OLS, 1% winsorisation, 2.5% trimming) and two samples (all firms, excluding the largest decile). The standardised indirect effect ranges from 0.087 to 0.149 with a median of 0.126, and every interval excludes zero. The spread is a useful reminder of how much the point estimate depends on measurement quality and sample handling even when the sign is stable. A real application should publish its own curve.

4.6 What the simulation shows and does not show

The simulation is useful for three reasons and misleading for a fourth. First, it confirms that the estimation pipeline recovers the structure that was built in: the first path is positive and rises with absorptive capacity, the second path is positive and larger for high-stringency markets, and the indirect effect is bounded away from zero. Second, it shows how wide the intervals are for a sample of a few hundred SMEs, particularly

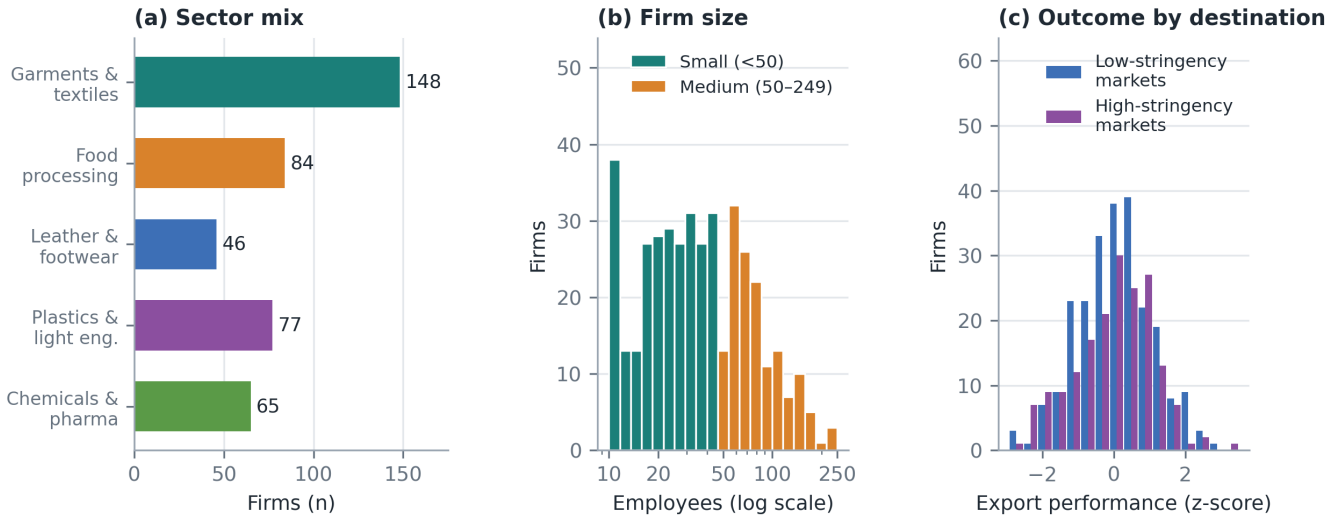


Figure 6. Simulated sample ($N = 420$): (a) sector mix, (b) distribution of firm size, (c) distribution of export performance by destination-market stringency.

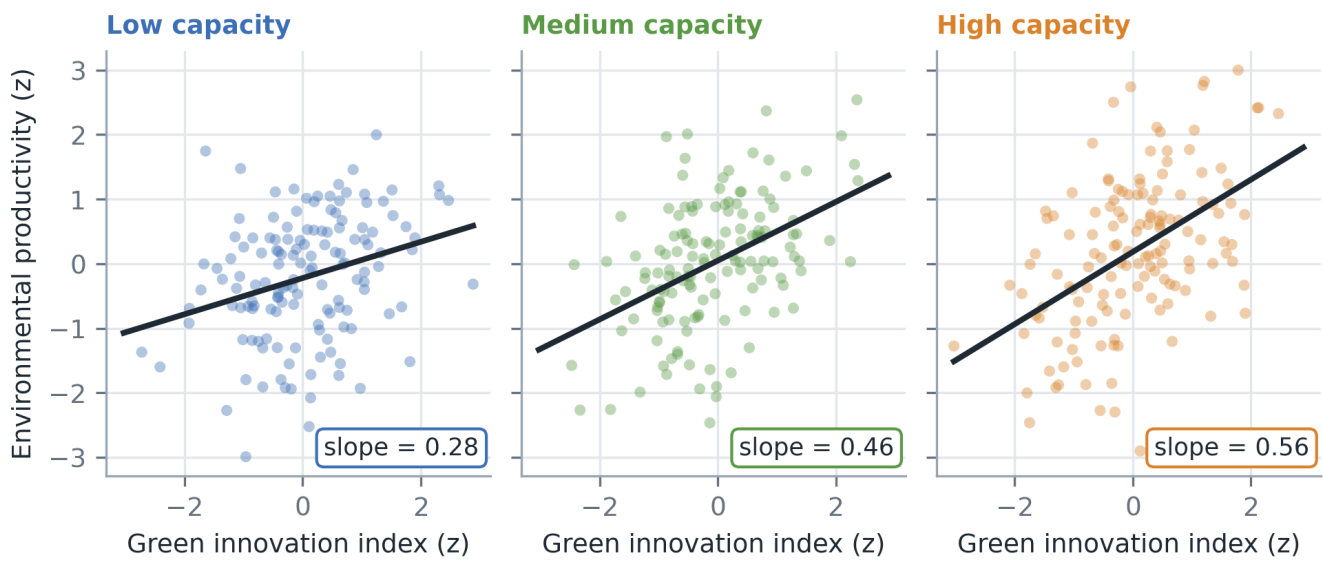


Figure 7. Simulated relationship between green innovation and environmental productivity by absorptive-capacity tercile. Lines are least-squares fits within each tercile.

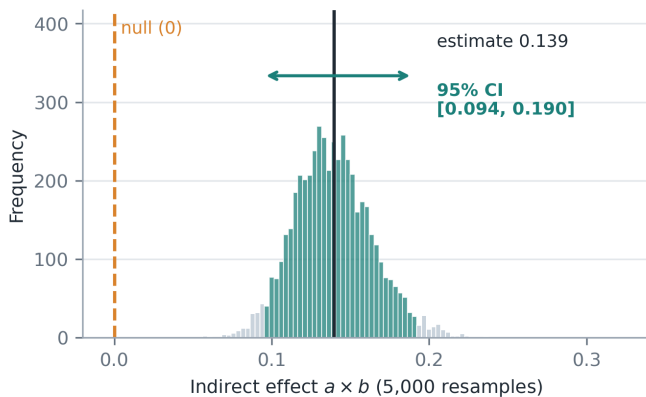


Figure 8. Bootstrap distribution of the simulated indirect effect $a \times b$. The shaded bars lie inside the 95% percentile interval.

inside sectors, which is the realistic precision a field study should expect. Third, it gives readers code to adapt, so that a real dataset can be run through the same steps. What it cannot do is say anything about the size of the true effect. The share mediated, for example, is a function of the assumed paths and would differ with other assumptions; the intervals describe sampling variation under a correctly specified model and do not reflect omitted confounders, measurement error in survey constructs beyond the noise that was added, or selection of firms into

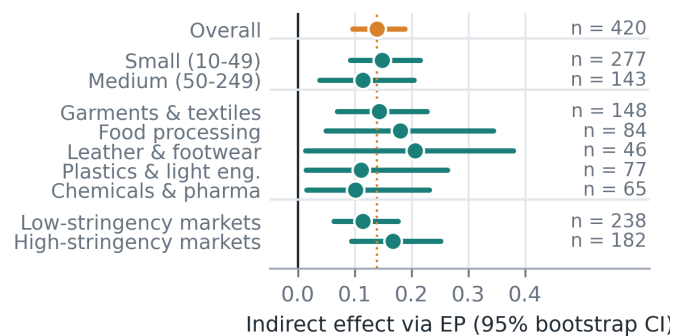


Figure 9. Simulated indirect effect by firm size, sector and destination-market stringency, with 95% bootstrap intervals.

exporting (?). For these reasons we treat the numbers as an illustration of reporting practice and not as a finding.

5. Discussion

The model offers a specific answer to a question that is usually answered with a slogan. Green innovation can help SME exports, but a large part of that help is expected to work through productivity: it is the improvement in value per unit of environmental pressure that translates into cost, compliance, credibility and quality advantages abroad.

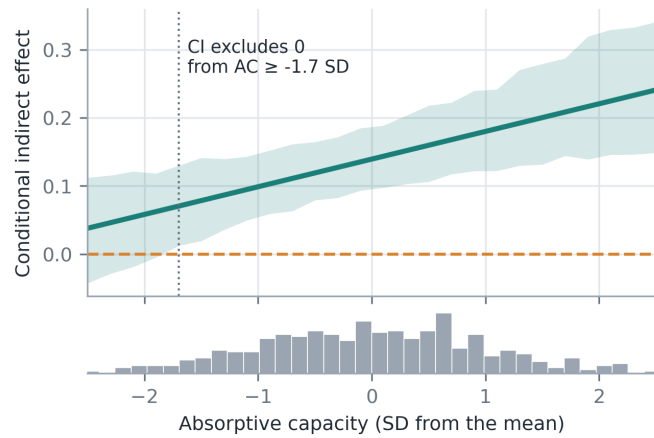


Figure 10. Conditional indirect effect across absorptive capacity, with 95% bootstrap band (600 resamples per grid point).

Where firms cannot turn innovation effort into EP gains, for example because they lack absorptive capacity, the export payoff is smaller. This reading is consistent with the resource-based view (?), with the weak form of the Porter hypothesis (Ambec et al., 2013), and with productivity-threshold models of trade (Melitz, 2003).

Three cautions apply. First, the mediation structure is a statistical decomposition; with observational data it has a causal interpretation only under strong assumptions about confounding of the EP–export relationship, which is why selection and instrument checks are part of the design. Second, EP is relative: because pressures are scaled by sector benchmarks, a firm can improve EP simply because its sector’s benchmark is lenient. Third, causality can run the other way. Exporting exposes firms to buyers’ standards and technology and may itself raise green innovation (?Love and Roper, 2015), so panel data with lags are needed.

5.1 Theoretical implications

The model contributes to three conversations. For the natural-resource-based view, EP supplies a measurable counterpart to capabilities that are otherwise described qualitatively: pollution-prevention capability should appear as more value created per unit of pressure (??Klassen and Whybark, 1999). For heterogeneous-firm trade models, EP adds an environmental dimension to productivity; a firm whose conventional productivity sits just below the export threshold might cross it by raising EP when buyers price or screen environmental performance (Melitz, 2003; Bernard and Jensen, 1999). For the Porter hypothesis, EP indicates where an innovation offset would show up in firm data, and the moderation by absorptive capacity is consistent with the view that offsets are not automatic but depend on the capability to exploit them (?Lanoie et al., 2011; ?). The framework is therefore an attempt to join three literatures that have so far been tested separately, and to do so with quantities a small firm can measure.

5.2 Managerial implications

SME managers should treat green investments as productivity projects and track EP as a management indicator, beginning with the metering and baseline steps that cost little. Capability-building (training, technical partnerships) is not a side issue: in the model it raises the return to every unit of green innovation. Managers selling into stringent markets have more to gain from EP and should prioritise documentation that buyers can audit. Figure 12 sets out an illustrative three-phase programme.

5.3 Policy implications

Support that only subsidises equipment may under-deliver if firms cannot absorb it. Programmes could pair finance with advisory services, help SMEs generate verifiable EP data (shared metering, standard calculation templates), and connect them to buyers’ audit schedules. Because the payoff appears larger for exporters in stringent markets, export-promotion and green-finance agencies could coordinate. Table 6 summarises the implications by actor.

Table 6. Implications by actor

Actor	Suggested action	Indicator
SME owners/managers	Meter pressures, compute EP, link projects to buyer requirements	EP trend; audit results
Buyers and retailers	Share benchmarks and provide technical support, not only codes	Supplier EP; defect rates
Banks and funds	Link green credit to measured EP gains	Loan-level EP change
Export and industry agencies	Bundle training, certification support and market access	Share of SMEs exporting
Statistical agencies	Publish linked energy–output–export data for research	Linked-data coverage

5.4 Emerging-economy context

The model is written for exporting SMEs in general but is motivated by settings such as Bangladesh, where garments and textiles lead the sector mix and where environmental requirements reach small suppliers mainly through buyers’ codes and audits rather than through domestic regulation. In such settings three features deserve attention. Many SMEs reach foreign markets indirectly, as subcontractors to larger exporters, so the pathway may run through the larger firm’s requirements and the SME’s EP may matter for retaining orders as much as for winning new ones. Technical staff and long-term finance are scarce (Hillary, 2004), which makes capability a binding constraint and strengthens the case for the moderator in H5. And the evidence base on green innovation and exports comes mostly from European and East Asian firms (Costantini and Mazzanti, 2012; Chen et al., 2006; Triguero et al., 2013), so the signs and sizes in the model should be tested locally before they are used to guide policy.

6. Limitations and Future Research

The main limitation is that the empirical section is simulated. The estimates in Section 4 recover parameters that we assumed, so they validate the estimation pipeline but say nothing about the real size of any effect. Other limitations are the cross-sectional design implied by the mediation model, the dependence of EP on the choice of pressures and benchmarks, possible common-method bias for survey constructs, and the limited external validity of evidence drawn from other settings to Bangladesh. Future work should (i) collect a matched survey and records dataset for exporting SMEs, (ii) use panel designs with lagged innovation and EP, (iii) compare ratio-based and frontier-based EP, (iv) test moderated mediation with real destination-market data, and (v) examine whether the pathway differs between direct exporters and indirect exporters that supply larger firms.

Three issues deserve particular care in a field study. The first is measurement: value added in currency units moves with prices and exchange rates, so EP should be deflated and checked against a physical-output version where products are homogeneous, and pressure weights should be varied to show that conclusions do not depend on one weighting. The second is timing. Process changes may raise EP within months while product redesign and certification take longer, and the export response may lag further, so cross-sectional mediation can understate or distort the indirect path; repeated surveys of the same firms are the natural remedy. The third is multiplicity of mediators. Cost, compliance, credibility and quality (Figure 5) are separate channels, and a model with several parallel mediators (Preacher and Hayes, 2008) could show which of them carries the effect for which kind of firm, something a single composite mediator cannot do.

A minimal reporting checklist for studies that use this framework would ask authors to state:

1. how EP was computed, which pressures and weights were used, and which sector benchmarks;
2. the source of each variable, and whether the mediator and outcome come from records or from the same respondent;
3. the sample frame, response rate and any weighting, with the number of firms in every subgroup that is reported;
4. the estimator, the number of bootstrap resamples and the random seed, with intervals for the indirect effect and for the index of moderated mediation;

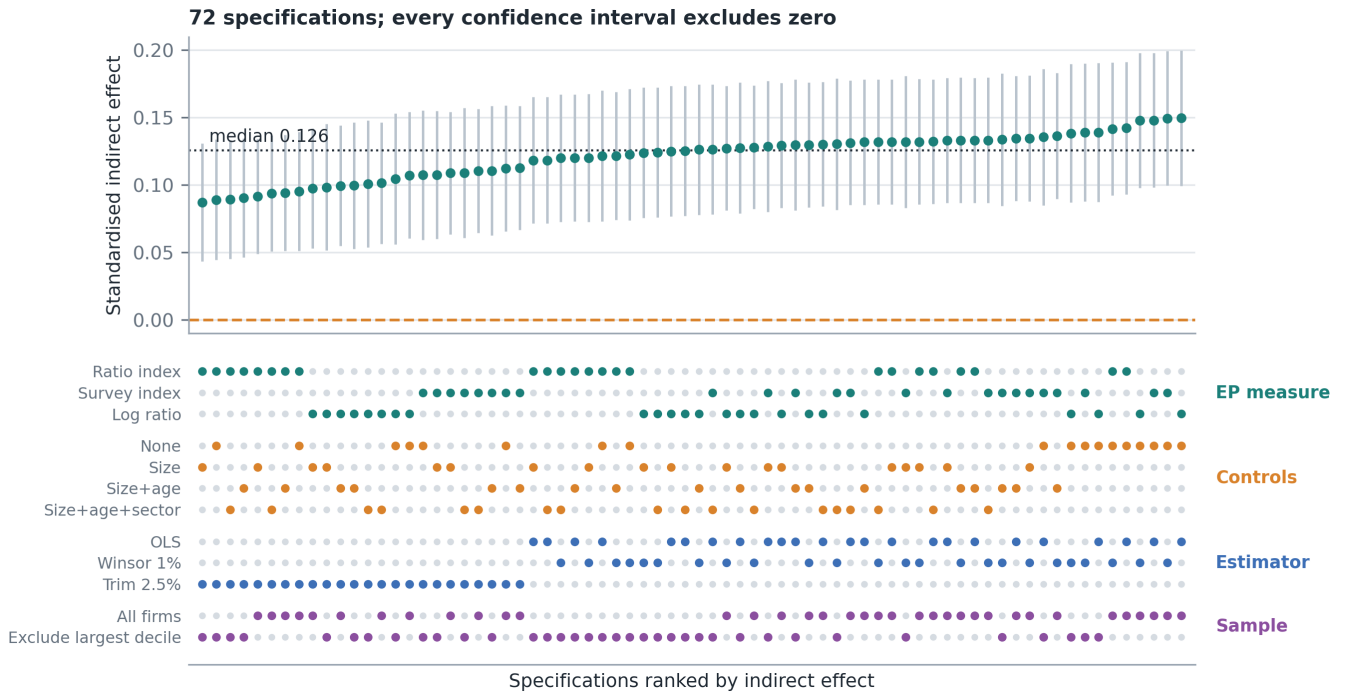


Figure 11. Specification curve for the simulated indirect effect (72 specifications). Top: estimates with 95% intervals ranked by size. Bottom: which analytic choice each specification uses.

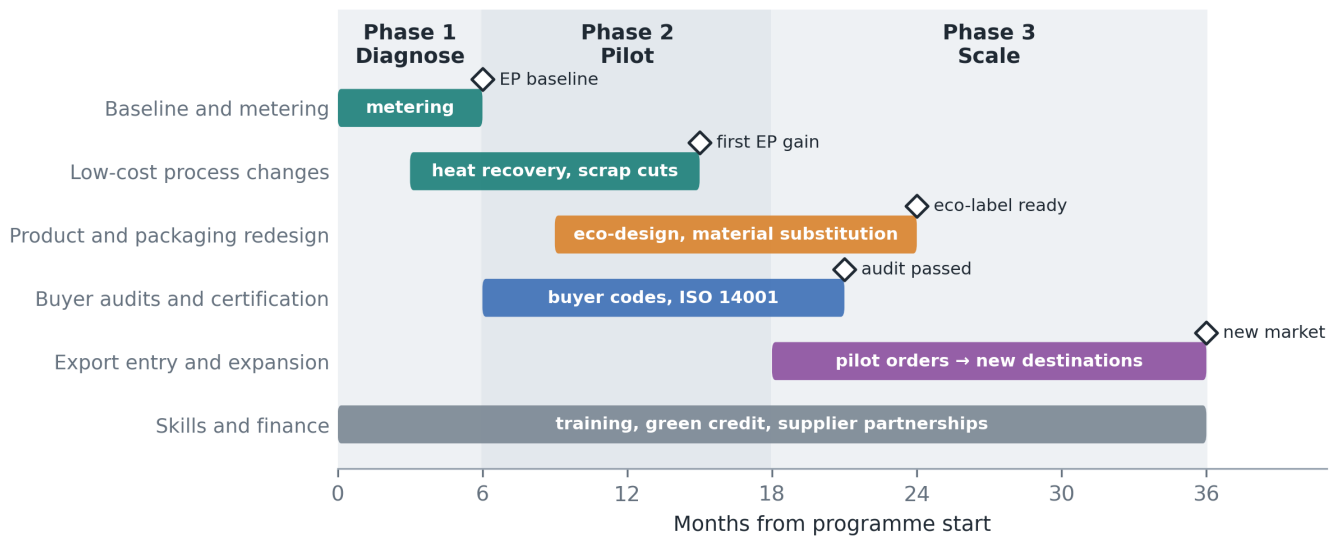


Figure 12. Illustrative 36-month roadmap for an SME: diagnose, pilot and scale across six workstreams, with milestones (diamonds). The timings are indicative, not empirical.

- the results of at least one specification curve or equivalent robustness exercise; and
- the main threats to causal interpretation, including selection into green innovation and into exporting.

7. Conclusion

This paper argues that environmental productivity is the missing link between green innovation and the export performance of manufacturing SMEs. Green innovation is expected to raise the value a firm creates per unit of environmental pressure, and that productivity gain is expected to be rewarded in foreign markets through cost, compliance, credibility and quality. The effect should be larger for firms with higher absorptive capacity and for those selling into stringent markets. We define EP, specify a moderated-mediation model with six hypotheses and a robustness protocol, and demonstrate the workflow on simulated data, where the indirect effect is 0.139 (95% CI 0.094–0.190) and accounts for roughly half of the total effect. The simulation is a demonstration, not evidence; the next step is to test the model on real SME data.

Appendix A. Simulation design and assumed parameters

The data in Section 4 are generated in four steps so that every number can be traced to an assumption. (1) Sector is drawn from fixed shares and employment from a truncated log-normal distribution on 10–249 employees; age is drawn from a gamma distribution. (2) Green innovation and absorptive capacity are standardised draws, each weakly related to firm size, and a share of firms is assigned to high-stringency destination markets. (3) Latent environmental productivity is generated from green innovation, absorptive capacity, their interaction, size, age and noise; the observed EP variable adds measurement error. (4) Export performance is generated from green innovation, latent EP (with a slope that depends on destination stringency), size, age and noise. Table 7 lists the assumed values. They were chosen for plausibility and illustration and are not estimates from any dataset.

Because these values are known, the exercise doubles as a check on the estimator: the recovered paths in Table 5 should be close to the assumed ones up to sampling error and to the differences in scaling that come from standardising variables, and they are. Researchers adapting the code can change any entry of Table 7 and observe how the indirect

Table 7. Assumed parameters of the data-generating process

Quantity	Value	Role in the model
Sample size	420	Simulated SMEs
Green innovation $\rightarrow$ EP	0.45	Path a at mean capacity
GI $\times$ AC $\rightarrow$ EP	0.15	Moderation of a (H5)
AC $\rightarrow$ EP	0.25	Direct capacity effect
EP $\rightarrow$ EXP, low stringency	0.28	Path b (H2)
EP $\rightarrow$ EXP, high stringency	0.48	Path b (H2, H6)
GI $\rightarrow$ EXP	0.12	Direct path c' (H3)
EP measurement noise (SD)	0.30	Observed vs latent EP
Survey-index EP noise (SD)	0.55	Alternative measure in Fig. 11
Share in high-stringency markets	45%	Destination mix

effect, the share mediated and the width of the intervals respond.

Data and Code Availability

No real firm-level data were collected. All simulated data, results and figures are reproduced by `sim.py` and `make_figures.py` (random seed fixed in the code), supplied with this manuscript.

Declaration of Interest

The authors declare no competing interests.

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