Banned in China, Born in Europe:
The waste import ban and Europe's plastics eco-innovation

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Abstract

We study a novel channel of policy-induced innovation operating through global environmental interdependence. In 2018, China abruptly banned most imports of foreign waste, disrupting global material flows and forcing exporting countries to internalize disposal constraints. Exploiting this policy as an exogenous shock and leveraging cross-country variation in pre-ban exposure, we examine how tightening disposal constraints affect plastics-related innovation in Europe. Using patent data for EU member states and Great Britain from 2009 to 2021, we develop a text-based approach to identify environmentally oriented plastics innovations that standard classifications poorly capture. We find that the shock reallocated inventive effort economy-wide toward plastics-related eco-innovations. Within that category, patenting activity shifted away from the adoption of foreign technologies and toward new domestic inventions, reflecting the increased need for locally adapted solutions, with stronger responses where waste pressures became more binding. This evidence highlights how constraints imposed abroad can reshape not only the level but also the origin and direction of domestic technological change, with implications for countries' positions in the global technology race.

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1 Introduction

In 2018, China abruptly closed its borders to most foreign waste, disrupting global material flows and tightening disposal constraints in exporting economies. In Europe, the immediate consequences were visible in strained waste management systems. Less visible, but economically consequential, was the reallocation of plastics-related eco-innovation by European firms that we document in this paper. Our findings suggest that foreign environmental policy shocks can redirect technological change by reshaping domestic production constraints, even without new domestic regulation or trade incentives. Rather than representing a purely environmental adjustment, the sudden loss of a critical processing stage triggered a broader technological reorientation. By altering which production techniques remain viable, such shocks influence the direction of inventive activity and, ultimately, countries' positions in the global technology race.

Much of the literature on policy-induced innovation treats domestic regulation or the diffusion of standards across peer economies as the primary sources of technological change. In these accounts, innovation is driven either by compliance with stricter rules at home or by the need to retain access to regulated foreign markets. As a result, foreign policies matter mainly insofar as they shape export opportunities and access to foreign demand, with less attention paid to mechanisms operating through domestic market conditions.

Plastics provide a particularly informative setting to study this mechanism. They are used across nearly all sectors of the economy, while the environmental externalities associated with plastics arise primarily at the waste-management stage rather than at production. As a result, end-of-life constraints depend heavily on cross-border trade in waste, making domestic market conditions especially sensitive to foreign waste-import policies. These features make plastics a useful setting for observing how externally imposed material constraints translate into domestic innovation incentives. Moreover, the same features characterize a broader class of materials and products – such as electronics, batteries, or composite materials – suggesting that related mechanisms may extend beyond plastics alone.

For decades, high-income countries relied on cross-border trade to manage plastic waste they could not recycle domestically, with China absorbing nearly half of global plastic waste exports (Brooks et al. 2018). China's 2018 waste-import ban– announced in 2017 and implemented in 2018 – abruptly closed this outlet, triggering a large and persistent decline in global waste trade (Figure 3) and forcing exporting countries to manage a greater share of waste domestically (Thakur 2026). While our empirical focus is China's 2018 ban, the implications extend beyond

this single case: when emerging economies stop serving as external processors of waste from richer countries, they can reshape innovation incentives abroad. As environmental constraints tighten, emerging economies are increasingly unwilling to serve as dumping grounds for waste or polluting industries from wealthier markets. Our analysis therefore speaks to a broader pattern of international interdependence in which foreign environmental policies that impose material constraints reshape domestic market conditions and induce technological change.

The mechanism we study also speaks to current debates on international technological competition. When access to a critical processing stage is restricted, firms do not simply substitute suppliers; they redirect research toward technologies that relax the new binding constraint. Foreign environmental policy shocks can therefore reshape not only the level of innovation but also its sectoral composition and origin. These shocks can contribute to the emergence of comparative advantage in green industries while stimulating technological developments in complementary industries (Fankhauser et al. 2013; Barbier 2025), but also potentially crowd out innovation in other activities. Whether technological capabilities are built through domestic invention or through the adoption of foreign technologies may in turn influence countries' dependence on external sources of innovation and long-run technological positioning. From this perspective, shifts in the direction of innovation constitute a first-order economic outcome rather than merely an intermediate step toward environmental performance.

We exploit China's 2018 waste-import ban as an exogenous shock to European market conditions. The policy originated in China's domestic environmental agenda, was announced only months before implementation, and applied uniformly to all foreign exporters. We study its effects across EU member states and Great Britain over 2009–2021. This European setting is well suited to causal evaluation because it combines broad institutional comparability with substantial cross-country heterogeneity in pre-ban exposure to the shock, including differences in plastics production, plastics consumption, and dependence on waste-export routes. Our empirical strategy therefore leverages differential exposure to a common external shock within a relatively harmonized regulatory environment.

To estimate its impact, we combine patent data with measures of exposure to the ban. Because the shock tightened waste-management constraints rather than altering demand for conventional plastics technologies, we focus on plastics-related eco-innovations such as recycling processes, waste-treatment techniques, and material substitutes, which are the technologies most likely to alleviate newly binding end-of-life constraints.. Given limitations of standard patent classifications in capturing plastics eco-innovation (Dussaux and Agrawala 2022), we develop a text-based approach that identifies environmentally oriented innovations such as

recycling processes and material substitutes which are most likely to respond to the shock.

We find that China's waste-import ban triggered a significant reorientation of European technological effort toward plastics-related eco-innovations, including recycling processes and material substitutes. Meanwhile, plastics innovation outside eco-innovation does not respond to the ban and general innovation beyond plastics falls post-ban, indicating that innovative efforts in the EU were redirected toward the specific and pressing constraint created by the ban. Notably, we observe a compositional shift toward domestic inventive activity, while foreign technology adoption becomes more selective: lower-value transfers decline and only the highest-value technologies continue to diffuse. This pattern suggests that many existing solutions developed under different waste-management conditions became poorly suited once disposal constraints tightened, creating a need for additional, locally adapted innovation.

Further supporting the mechanism, technological adjustment is strongest where the tightening of disposal constraints became most binding. Responses are particularly pronounced in countries that were more reliant on China as an external waste outlet prior to the ban and in high-consumption economies, where the sudden loss of foreign processing capacity translated into sharper domestic waste pressures. Countries that continued to rely on waste-export markets after the ban also exhibit stronger responses, consistent with the increased selectivity and cost of remaining disposal outlets following the collapse of low-quality export routes; this effect is particularly pronounced for waste exports directed to the European Union, where stricter environmental regulations further raise disposal costs and reinforce incentives for innovation. A different adjustment margin emerges upstream, on the production side: in more export-oriented plastics-producing economies, where before the ban waste pressures had been externalized through foreign markets, weakening incentives to build domestic waste-management technological capabilities. As a result, the post-ban response in these economies operates primarily through foreign technology adoption rather than new domestic invention.

Our findings contribute to several strands of the literature. We build on work using patent data to study technological responses to environmental pressures (Popp 2002; Calel and Dechezleprêtre 2016) and extend research on policy-induced innovation that emphasizes domestic regulation and export-oriented responses to environmental stringency (Popp 2006; Johnstone et al. 2010; Dechezleprêtre et al. 2013; Aghion et al. 2016; Brunel 2019).

We also contribute to the literature on international policy spillovers operating through material constraints. While prior work has largely focused how environmental regulation in high-income countries affects developing economies via technology transfer or export-oriented innovation (Dechezleprêtre and Glachant 2014; Verdolini and Bosetti 2017), we document a

reverse channel in which unilateral environmental policy implemented by an emerging economy redirects innovation in advanced economies toward domestically binding constraints rather than export compliance. By incorporating this reverse direction of influence, our results broaden existing analyses of the Porter Hypothesis and models of directed technical change (Porter and van der Linde 1995; Acemoglu et al. 2012), while remaining consistent with a broader shift in global environmental governance in which emerging economies increasingly act as regulatory agenda-setters rather than passive recipients of policy spillovers (Sun 2016; Yang et al. 2023).

The remainder of the paper is structured as follows. Section 2 provides background on the plastics industry, China's 2018 ban on waste imports, and the resulting disruption of global waste trade. Section 3 introduces the identification strategy and the econometric model. Section 4 describes the data construction and sources, while Sections 5 and 6 report the main findings and robustness analyses. Finally, Section 7 discusses the broader implications of the results and concludes.

2 Plastics waste trade and the China import ban

The world produces roughly 400 million tonnes of plastic each year, around two-thirds of which consists of short-lived products that rapidly become waste,[1] while global plastics use and waste are projected to nearly triple by 2060 (OECD 2022b). This accelerating expansion in plastics disposal generates persistent and geographically diffuse risks for biodiversity, ecosystem functioning, human health, and economic activity.

Plastic waste is generated largely at the consumption stage rather than during production. Because they are used extensively as both intermediate and final goods across a wide range of downstream sectors, plastics represent an economy-wide challenge rather than one confined to the plastics industry itself. Most plastic waste originates from post-consumer sources such as packaging and consumer products, while waste generated during industrial production is often recycled internally within manufacturing processes (OECD 2022a; Plastics 2024; Products 2022). At the same time, domestic recycling capacity has historically been limited and uneven across countries. As a result, the geographical distribution of waste generation does not necessarily coincide with the availability of cost-effective processing infrastructure. International trade in plastic waste therefore emerged as an important adjustment margin, allowing counties to externalize part of their disposal burden.

[1] https://www.unep.org/news-and-stories/story/quiz-how-much-do-you-know-about-plastic-pollution-crisis

Prior to 2018, global trade in plastic waste was highly concentrated, with China serving as the dominant importing country. By 2016, China was receiving over 45% of the world's plastic waste, much of it from the United States, Japan, and the European Union (Brooks et al. 2018). Access to Chinese processing capacity therefore played a central role in shaping disposal strategies for major exporters. Mounting domestic concerns about pollution, environmental degradation, and public health eventually led the Chinese government to reassess this dependency (Velis 2014; Brooks et al. 2018; Li and Liu 2021; Wen et al. 2021; State Council of the People's Republic of China 2017). Following the 2014 Operation Green Fence efforts to improve the quality of imported recyclable materials, the government announced restrictions on imports of multiple categories of foreign waste in July 2017, with a formal ban on most plastic waste imports taking effect in January 2018 (Li and Liu 2021). Enforcement intensified during the announcement period as inspections tightened and shipments were rejected, leading to a rapid contraction in waste shipments.

The ban had substantial global effects on waste trade and recycling practices. In the immediate aftermath, stockpiles of recyclable waste accumulated at ports and processing centers across Europe, North America, and parts of Asia (Walker et al. 2022), while prices for recyclable plastics fell and municipal recycling programs faced logistical and financial pressures. Evidence suggests that exporting countries responded by internalizing waste management and strengthening domestic regulation, although disruptions also increased mismanaged plastic waste in some settings (Shan et al. 2020; Li et al. 2020a; Naeem et al. 2021; Brooks et al. 2021; Green and Smith 2020; Kwon and Lee 2021).

Panel (a) of Figure 3 documents the sharp decline in European plastic waste exports following the policy announcement. Exports to China collapsed beginning in late 2017 and remained depressed after implementation of the ban. Aggregate exports to alternative destinations did not increase sufficiently to offset the loss of Chinese demand (panel b), implying a substantial reduction in access to external waste-processing capacity. As a result, European countries were required to manage a larger share of plastic waste domestically, tightening end-of-life constraints across sectors that rely on plastics as inputs.

European policymakers framed China's import restrictions as a major disruption to global recycling markets and used them to justify renewed efforts to strengthen domestic waste management. The 2018 EU Plastics Strategy, introduced under the Circular Economy Action Plan, emphasized expanding recycling capacity, improving product design, and promoting innovation in plastic alternatives (European Commission 2018a). Official policy documents explicitly linked these initiatives to the loss of external disposal options following China's restrictions

(European Commission 2018b), suggesting that European regulatory responses formed part of the broader adjustment process triggered by the shock. However, the Strategy itself was a non-binding roadmap rather than an immediately enforceable regulation. Concrete legislative measures were introduced only gradually and largely after the end of our sample period. For example, mixed or contaminated plastic waste was reclassified as "amber-listed" beginning in January 21, restricting its export,[2] and a near-total ban on the export of plastic waste outside the EU was approved only in 2022.[3] While the Chinese ban therefore increased policy attention to plastics and circularity in Europe, it did not generate an immediate discrete shift in regulatory stringency comparable to the abrupt tightening of disposal constraints following the collapse of exports to China. In the empirical analysis, we nevertheless assess the sensitivity of our results to the timing of European policy developments.

European Union member states provide a particularly suitable setting to study this mechanism because they operate under a largely harmonized environmental regulatory framework. While implementation and enforcement may vary at the national level, core rules governing waste management, product standards, and environmental protection are set at the EU level. This institutional structure limits cross-country variation in baseline regulatory stringency and reduces concerns that heterogeneous domestic environmental policies are confounding the estimated innovation response.

3 Empirical framework

3.1 Innovation under a foreign material-constraint shock

Existing work shows that technological change responds to shifts in product demand and environmental regulatory stringency (Popp 2002; Acemoglu et al. 2012; Aghion et al. 2016; Calel and Dechezleprêtre 2016). This paper studies an additional channel: changes in the material constraints faced by firms. In models of induced and directed technical change, innovation reallocates toward technologies that relax the new binding bottlenecks rather than expanding uniformly across technological domains. When an input or disposal margin becomes scarce or a disposal margin becomes more costly or constrained, the relative profitability of innovation that alleviate the constraint increases, redirecting inventive effort even in the absence of changes in

[2] Commission Delegated Regulation (EU) 2020/2174: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R2174.

[3] https://www.politico.eu/article/eu-agrees-ban-plastic-waste-export/.

aggregate research investment. China's 2018 ban on imports of foreign plastic waste represents a sharp example of such a material-constraint shock. By abruptly removing access to the world's largest external outlet for low- and medium-quality plastic waste, the policy increased the implicit cost of waste disposal for exporting economies. Unlike conventional environmental regulation, the ban did not impose new compliance requirements on European firms, nor did it operate by restricting export opportunities or changing foreign consumer demand. Instead, it altered material conditions at home by removing a key adjustment margin in global waste markets. Firms that had relied on exporting waste to manage end-of-life pressures were forced to internalize these constraints, increasing the returns to technologies that reduce, manage, or circumvent waste-generation bottlenecks.

This mechanism yields clear predictions about the direction of technological adjustment. First, the tightening of disposal constraints should lead to a reallocation of innovative effort toward environmentally oriented plastics technologies – including recycling processes, waste-treatment methods, and material substitutes – rather than to plastics innovation more broadly. Because the shock operates at the end-of-life stage, innovations that improve performance or production efficiency without addressing waste management are not expected to respond systematically.

Second, the innovation response should be stronger in countries where the ban tightened material constraints more sharply. Economies that were more exposed to external waste-processing capacity prior to the policy – for example through higher reliance on waste exports or greater domestic plastics consumption – faced a larger increase in the shadow cost of disposal once foreign outlets contracted. In an induced-innovation framework, these differences in exposure translate into heterogeneous incentives to redirect inventive activity toward disposal-constraint-relaxing technologies. Third, the response should vary along the plastics value chain. Downstream process innovations, such as recycling, sorting, or waste-conversion technologies, directly expand domestic disposal capacity and therefore address the most immediate bottleneck created by the ban. Upstream product innovations – including redesigning plastics to be more recyclable or substituting toward alternative materials – mitigate future waste pressures without immediately expanding disposal capacity. As a result, innovation responses are expected to be strongest and most immediate for process-oriented eco-innovations, with complementary but adjustments in product-oriented innovations operating over longer adjustment horizons.

The empirical analysis tests these predictions by examining whether plastics-related eco-innovation increases following China's waste-import ban, whether the response varies systematically with countries' pre-existing exposure to the shock, and whether it is concentrated in

downstream process technologies.

3.2 Identification and empirical design

To evaluate how material-constraint shocks affect innovation, we exploit China's 2018 ban on imports of foreign plastic waste as a sudden tightening of disposal conditions faced by European economies. The policy was announced in mid-2017 and became legally binding on January 1, 2018, abruptly restricting access to the world's largest external waste-processing market. Because the ban applied uniformly across trading partners and was motivated by domestic environmental enforcement priorities in China, it represents a plausibly exogenous shift in the material environment confronting European firms.

Our empirical strategy leverages cross-country heterogeneity in pre-existing exposure to the shock. European economies differed substantially in their reliance on external waste-processing capacity and in the scale of domestic plastics circulation prior to the ban. Countries that exported larger volumes of plastic waste to China or exhibited higher levels of plastics consumption faced a greater increase in the shadow cost of waste management once external disposal options contracted. In an induced-innovation framework, these differences translate into heterogeneous incentives to redirect inventive effort toward disposal-constraint-relaxing technologies.

Identification therefore relies on differential responses to a common external shock. We compare changes in plastics-related innovation across countries with varying degrees of exposure before and after the implementation of the ban. This approach isolates the effect of tighter disposal constraints from other contemporaneous developments affecting innovation at the European or global level. Importantly, the identifying variation is entirely within Europe. Even if aggregate waste exports from advanced economies contributed to China's broader regulatory agenda, individual European countries accounted for only a small share of total imports as documented in Figure 3. The timing and scope of the China ban are therefore better understood as responses to system-wide environmental pressures rather than to variation across European partners.

A key empirical consideration concerns the timing of adjustment. Waste-trade flows began to respond following the policy announcement in 2017, reflecting the short-run feasibility of redirecting shipments. Innovation responses, however, are likely to occur with delay due to planning horizons, R&D investment cycles, and the lag between inventive activity and patent filing. We therefore treat 2018 as the start of the treatment period in baseline specifications.

This timing assumption is supported by empirical patterns documented below, which show a clear reorientation of innovation activity beginning after the ban became legally binding. We nevertheless assess sensitivity to alternative policy dates corresponding to earlier partial restrictions and to the announcement of the ban.

We also address several potential alternative explanations. Once concern is that global waste-trade reallocation following the collapse of exports to China may have partially mitigated the tightening of disposal constraints. Rather than constituting competing explanations, however, these adjustments indicate different responses to the same underlying policy shock. Capacity constraints and regulatory tightening in these destinations – particularly in parts of Southeast Asia – further reduced the availability of external processing outlets. Importantly, trade diversion and third-country regulation affected exporters broadly and contemporaneously, whereas our empirical results vary systematically with countries' pre-ban exposure to waste exports, domestic plastics consumption, and trade orientation.

A second concern is that European policy initiatives in the plastics domain accelerated after 2018. These measures were explicitly framed as responses to the China ban, and the most binding regulations were implemented only in the last year or after the end of our sample period. We therefore interpret domestic regulatory developments primarily as transmission channels through which the external shock affected innovation incentives rather than a competing explanation. Nonetheless, we provide robustness checks assessing whether the observed innovation patterns can be attributed to broader European policy trends independently.

Finally, broader technological trends and structural differences across countries are accounted for through controls, fixed effects, and country-specific trends that absorb persistent heterogeneity in innovation capacity and economic structure. We further implement placebo tests using innovation outcomes that should not respond to changes in waste-management conditions, allowing us to verify that the estimated effects are specific to plastics-related eco-innovation.

3.3 Baseline specification

We begin by estimating a reduced-form specification that examines whether plastics-related eco-innovation shifted across European economies following the tightening of disposal constraints induced by China's waste-import ban. Because the policy represented an externally imposed and plausibly exogenous change in the material environment facing European firms,

this specification provides an initial assessment of whether innovation trajectories deviate from their pre-existing paths after the shock.

Using annual data for the 27 EU Member States plus Great Britain between 2010 and 2021, we estimate:

$$\log(\text{Patents})_{i,t} = \beta_0 + \beta_1 Ban_t + \boldsymbol{\gamma}'\mathbf{X}_{i,t} + \mu_i + \delta_i t + \epsilon_{i,t} \tag{1}$$

The dependent variable, $\log(\text{Patents})_{i,t}$, is the natural logarithm of the annual count of plastics-related eco-patents in country i and year t, weighted by patent family size to account for value. We additionally consider alternative outcomes that enable us to distinguish whether the ban primarily stimulates domestic inventive activity or encourages reliance on foreign technologies, and whether the shifting incentives might primarily affect high-value, internationally recognized inventions.

The key explanatory variable is and indicator Ban_t equal to one from 2018 onward and zero otherwise. We define the post-treatment as beginning in 2018, when the ban became legally binding and disposal constraints were most clearly internalized. This timing is consistent with the delayed adjustment expected for innovation outcomes relative to the rapid reallocation of waste-trade flows following the policy announcement. As robustness checks, we consider alternative treatment timings corresponding to partial restrictions introduced in 2014 and to the July 2017 announcement of the ban, to assess potential anticipatory responses.

Because the policy shock affected all European countries simultaneously, including year fixed effects would absorb the aggregate post-ban shift that this reduced-form specification is designed to capture. Instead, the coefficient β_1 is identified from deviations in innovation activity from country-specific pre-trends following the ban. We therefore include country fixed effects μ_i to control for time-invariant differences in innovation capacity and industrial structure, as well as country-specific linear time trends $\delta_i t$ that capture gradual changes in plastics-related innovation trajectories. The vector of controls $\mathbf{X}_{i,t}$ includes GDP, population, sectoral composition, overall (non-plastics) patenting activity, and plastics waste exports.

The model is estimated by Ordinary Least Squares (OLS), with standard errors clustered at the country level (Cameron and Miller 2015). As a robustness check, we also estimate Poisson Pseudo-Maximum Likelihood (PPML) specifications, which accommodate the count nature of patent data and yield consistent estimates under heteroskedasticity (Santos Silva and Tenreyro

2006).

While the ban constitutes an exogenous tightening of disposal constraints, this specification does not exploit cross-country differences in exposure to identify causal treatment intensity. Rather, it provides evidence on whether innovation trajectories across Europe shift discontinuously following the shock, conditional on pre-existing trends and observable determinants of patenting activity. To more directly assess the causal mechanism implied by the conceptual framework – namely that innovation responses should be stronger where disposal constraints tightened most sharply – we next extend this framework to allow treatment effects to vary systematically with countries' pre-existing exposure to plastics production, consumption, and waste trade.

3.4 Heterogeneous treatment effects

To exploit the identifying variation described in Section 3.2, we extend the baseline specification to allow the effect of the ban to vary systematically with countries' exposure to tighter waste-management constraints. Although the policy represented a common external shock, its economic consequences depended on how strongly individual economies relied on foreign disposal outlets and on the scale and organization of plastics circulation within their domestic production and consumption systems. In particular, the increase in the shadow cost of waste disposal was shaped both by pre-existing structural exposure – such as reliance on exports to China and the volume of plastics entering domestic waste streams – and by the subsequent reconfiguration of waste-trade patterns as countries attempted to redirect flows toward alternative destinations. By interacting the post-ban indicator with measures capturing these different margins of exposure, the empirical framework allows treatment intensity to vary across countries and therefore tests whether innovation responses were stronger where material constraints tightened most sharply.

The interaction specification is given by:

$$\log(\text{Patents})_{i,t} = \beta_0 + \beta_1 Ban_t + \beta_2\big(Ban_t \times \log(\text{Plastics}_{i,t})\big) + \boldsymbol{\gamma}'\mathbf{X}_{i,t} + \mu_i + \delta_i t + \epsilon_{i,t}. \quad (2)$$

where $Exposure_{i,t}$ denotes alternative measures of countries' vulnerability to tighter waste-management constraints. The interaction coefficient β_2 captures whether innovation responses

following the ban were stronger in economies where disposal conditions deteriorated more sharply.

We consider three complementary dimensions of exposure. First, we construct a measure of direct reliance on China as a disposal outlet prior to the policy. This indicator identifies countries in the top quintile of average plastic waste exports to China over the period 2009—2017 and proxies for the immediate loss of access to foreign recycling capacity following the ban.

Second, we capture domestic waste pressure using measures of plastics flows within each economy. Domestic plastics consumption proxies for post-consumer waste generation and therefore for the intensity of end-of-life constraints once external disposal options contract. Domestic plastics production captures upstream exposure through increased domestic waste accumulation when export routes are curtailed. The export-to-production ratio reflects the extent to which plastics-related activity is oriented towards foreign markets and the degree to which waste burdens were previously externalized.

Third, we allow treatment effects to vary with time-varying plastic waste exports disaggregated by destination and by measurement unit in order to capture how adjustment operated through evolving waste-trade channels. We distinguish two destination groups: (i) intra-European exports including Great Britain, and (ii) exports to the rest of the world including China. Interacting these destination-specific export measures with the post-ban indicator captures how the tightening of disposal constraints differed depending on countries' reliance on particular external outlets and the subsequent reconfiguration of waste-trade patterns.

For each destination group, we construct waste-export measures expressed both in value (million euros) and in physical quantity (metric tons). This distinction is economically important. Quantity measures capture the physical reallocation of waste and therefore the material tightening of disposal capacity induced by the ban, while value measures reflect changes in the economic composition and unit values of residual export markets. Comparing interaction estimates across these dimensions allows us to assess whether innovation responses were primarily driven by the physical reallocation of waste or by shifts in the structure of waste-trade opportunities.

Together, these interaction specifications operationalize the mechanism emphasized in the conceptual framework. Because the waste-import ban represents a common external shock, identification of differential treatment effects relies on cross-country variation in these exposure measures. If the tightening of end-of-life constraints increased the relative profitability of waste-constraint–relieving technologies, innovation responses should be strongest in economies where

reliance on external disposal capacity and plastics throughput made the adjustment pressure most severe.

4 Data Construction and Sources

4.1 Patents measurement and data

4.1.1 Identifying plastics-related eco-innovations

To measure innovation responses to the tightening of disposal constraints, we construct a novel dataset of plastics-related eco-innovations, defined as environmentally oriented innovation, based on patents data. A central requirement for our empirical strategy is to isolate innovations that alleviate end-of-life material pressures. Because China's waste-import ban affected waste management rather than product demand or production efficiency, the relevant technological margin includes recycling processes, waste-treatment technologies, and materials designed to improve recyclability or reduce environmental impacts.

A natural starting point for identifying eco- innovation is the Cooperative Patent Classification (CPC) system, in particular the Y02 class for climate-related technologies. However, CPC-based measures present important limitations in this context. The Y02 class focuses primarily on greenhouse-gas mitigation and therefore only partially capture plastics-related eco-innovation (Dussaux et al. 2023). Moreover, revisions to environmental classifications — including updates in 2015, 2018, and 2020 within our sample period (Barbieri et al. 2025) — and differences in adoption across jurisdictions can introduce time-varying and cross-country measurement inconsistencies. Many plastics-related eco-innovations also occur in downstream applications such as packaging or consumer goods and are not systematically captured by codes primarily covering polymer technologies. These limitations are particularly consequential in our setting, where misclassification could bias estimates based on shifts in innovation trajectories and differential exposure to disposal constraints.

To address these issues, we develop a three-step text-based methodology that builds on Dussaux and Agrawala (2022) to identify plastics-related eco-innovations based on patent titles and abstracts. In a first step, we select patents using broad plastics-related keywords (e.g., plastic(s), polymer(s)). In a second step, we identify plastics-related eco-innovations within this sample by requiring the co-occurrence of plastics-specific keywords (e.g., polyethylene, chemical

recycling) and environmentally oriented keywords (e.g., recyclable, depolymerization), thereby ensuring both technological relevance and environmental content.

In the third step, we extend Dussaux and Agrawala (2022) by distinguishing between product and process eco-innovations using separate expert-validated keyword lists (Table A15). Product eco-innovations refer to new materials or designs that improve recyclability or enable substitution toward more sustainable or biodegradable alternatives. Process eco-innovations refer to changes in manufacturing, recycling, or waste management that reduce energy use, emissions, or waste generation. This distinction allows us to examine whether adjustment to the China ban differed between product and process eco-innovation along the plastics value chain.

This three-step identification procedure is illustrated in Figure 5. Validation exercises comparing our approach to the four CPC codes commonly used to capture plastics-related environmental technologies are reported in Appendix Tables A17, A18–A21, and Table 1.[4] They show that the text-based approach captures a substantially broader set of relevant innovations across a wider range of sectors while limiting false positives.

Figure 6 compares CPC-based and text-based classifications over time and reveals two limitations of CPC-based measurement for our empirical setting. First, CPC coverage expands around 2018, coinciding with the implementation of China's waste-import ban, implying that revisions in the assignment of environmental CPC codes could mechanically generate apparent post-ban increase in eco-innovation even in the absence of real technological adjustment. Second, CPC classifications disproportionately miss product-oriented eco-innovations, identifying only a small share of the innovations captured by the text-based method. These patterns suggest that CPC-based measures would distort both the timing and composition of estimated innovation responses. The implications for empirical results are discussed in Section 6.1.

4.1.2 Patent data

We draw on the EPO Worldwide Patent Statistical Database (PATSTAT v. Spring 2024), which contains patent applications filed at national offices of all EU Member States and Great Britain, as well as at the European Patent Office (EPO). Patents are assigned to countries and years based on their filing date to align with the timing of inventive activity and avoid distortions from differing examination processes across jurisdictions. For each patent, we observe all offices

[4]Plastics-related environmental innovation is represented by just four of the more than 300 Y02 subcategories: Y02P 20/143, Y02W 30/62, Y02W 30/50 and Y02W 90/10.

where it is filed and whether it claims priority from a previous application.

To capture the economic significance of inventions, patent counts are weighted by patent family size—the number of countries in which a patent is filed—which reflects broader geographic protection and is commonly interpreted as a proxy for value. While citations provide an alternative measure of importance, cross-country differences in citation practices make family size more suitable for international comparisons (de Rassenfosse et al., 2016).

To identify the very highest-value inventions, we further focus on "triadic" patents – those filed simultaneously in the United States, Europe, and Japan. Filing in multiple major jurisdictions entails substantial costs and signals an expectation of broad commercial value. Restricting attention to triadic patents reduces noise from low-value or purely local filings and provides a more comparable measure of international significant inventive activity.

We also distinguish between patents that represent new domestic inventions and those that reflect technology transfer. A patent is classified as a new invention if it is the priority filing, and as a transfer if it claims priority from an earlier foreign filing. This distinction captures whether innovation responses reflect local inventive activity or the adoption of technologies developed elsewhere, which may differ in their suitability to domestic waste-management conditions following the ban.

Figure 7 shows that eco-innovation in Europe draws on both indigenous inventive capacity and international technology transfer, with substantial heterogeneity across countries. Germany stands out as the main sources of new inventions in the plastics sector, reflecting their strong research and industrial bases, while Eastern European member states rely more heavily on foreign technology adoption. Meanwhile, Great Britain, Spain and France appear as important hubs for both domestic inventions and the uptake of foreign innovations. This variation provides an additional margin along which responses to the shock may differ.

Patent data are not without limitations. Within the EU, inventors may file either at national offices or through the EPO. Since 2009, EPO filings automatically cover all member states, with only minor translation requirements. Because our dataset begins in 2010, we assign EPO patents to all EU member states.[5] This method may overstate patenting activity in some countries where patents are legally valid but not actively utilized, so we perform robustness checks excluding EPO patents. Finally, while some inventions may remain unpatented to protect trade secrets, studies suggest this is uncommon (Dernis and Khan 2004). Overall,

[5]Although EPO membership evolved over time, by 2010 all EU Member States were members of the EPO (see https://www.epo.org/en/about-us/foundation/member-states)

patent data provide a reliable measure of a country's technological knowledge (Griliches 1990).

4.2 Heterogeneous exposure through plastics trade and waste exports

To examine how China's waste-import ban affected plastics eco-innovation through different exposure channels, we construct measures capturing domestic waste pressure and trade-mediated reliance on external disposal routes. Although the policy shock was common across countries, its economic impact depended on the scale of plastics circulation within national economies and on pre-existing dependence on foreign waste-processing capacity.

Direct exposure to the China ban. We define direct exposure to the China ban as an indicator for countries in the top quintile of average plastic waste exports to China over the period 2009–2017. This variable proxies for reliance on China as a disposal outlet prior to the ban and captures heterogeneity in the immediate loss of access to external waste-processing capacity.

Domestic plastics flows. We next construct three measures capturing domestic plastics circulation. Domestic plastics consumption – defined as production plus imports minus exports – proxies for post-consumer waste pressure, as most plastic waste arises after use. Domestic plastics production captures the scale of upstream plastics activity and indirect exposure to tighter disposal options when export routes contract. Finally, the ratio of plastics exports to domestic production reflects the extent to which the plastics industry is oriented toward foreign markets and the degree to which waste associated with that production was effectively externalized prior to the ban.

Destination-specific measures of plastic waste exports. To capture how adjustment operated through evolving trade channels, we construct time-varying measures of plastic waste exports by destination. Using bilateral trade data, we disaggregate plastic waste exports by destination into: (i) intra-European exports including Great Britain, (ii) exports to the rest of the world excluding China, and (iii) exports to the rest of the world including China. Interacting these time-varying destination-specific export measures with the China-ban indicator allows us to assess how innovation varied with countries' reliance on particular foreign disposal routes

and the subsequent reconfiguration of waste-trade patterns following the ban.

Data sources and definitions. To construct these variables, we draw on data from EXIOBASE, a multi-regional environmentally extended supply-use and input-output database covering 44 countries and detailed product categories (Stadler et al. 2018). We treat "plastics, basic" (code p.24.a) and "rubber & plastic products" (code p.25) jointly as our measure of plastics. Plastics waste can be identified through "plastic waste for treatment: incineration" (p.90.1.c).[6] From these data, we compile plastics production, imports, exports, and waste exports in value (million euros). As a complement, we assemble quantity-based measures of plastic waste exports in metric tons using BACI data for HS code 3915, which captures the mass of material moved through waste transfers.

Value versus quantity. The distinction between export values and quantities has important implications. Quantity measures capture the physical tightening of disposal capacity resulting from the contraction of foreign recycling outlets. Value measures capture changes in the economic viability and composition of export markets. Post-ban increases in plastic waste unit values largely reflect quality selection rather than tighter demand (Li et al. 2020b; Wang et al. 2024). China's import restrictions removed low-grade and contaminated plastic waste from international trade while allowing only highly sorted, cleaner materials to remain exportable, mechanically increasing average unit values even as traded volumes collapsed. Therefore, quantity and value measures capture distinct dimensions of exposure: quantities reflect physical waste reallocation, while values capture changes in the economic viability and quality composition of export markets.

In the baseline specifications, waste exports enter as controls measured in value terms, but quantity-based measures yields qualitatively identical results. We present both measures only in the interaction analysis, where results do diverge meaningfully across specifications and these differences help distinguish between economic and physical constraints channels.

4.3 Other controls and fixed effects

To account for cross-country differences that may influence plastics trade and innovation outcomes, we include a set of controls capturing economic scale, sectoral composition, and baseline innovative capacity, alongside country fixed effects and country-specific time trends.

[6]The other code for plastic waste is "plastic waste for treatment: landfill" (p.90.5.c) but landfill waste cannot legally be exported.

We include the logarithm of GDP (in millions of euros) and population (in millions of people) from Eurostat to proxy for differences in market size, industrial activity, and the overall scale of innovation systems. The shares of GDP accounted for by agriculture and manufacturing (Eurostat) capture structural differences in plastics intensity and exposure to environmental regulation across economies. To account for general technological dynamism, we control for overall patenting activity excluding plastics-related patents, constructed from PATSTAT. This variable proxies for broader innovative capacity while avoiding mechanical correlation with the dependent variable. Controlling for general innovation trends helps distinguish plastics-specific eco-innovation responses from broader technological dynamism that may be unrelated to the China ban.

We additionally control for the value of plastics waste exports using data from EXIOBASE, which captures participation in international waste trade both before and after the ban. Conditioning on waste exports helps distinguish reliance on foreign outlets for managing waste from reliance on foreign demand for plastics production. It also accounts for trade reallocation and regulatory responses in alternative destinations – particularly in South East Asia – following the China ban.[7]

Country fixed effects absorb time-invariant national characteristics such as geography, long-standing institutional quality, historical industrial structure, and cultural attitudes toward consumption and waste. Country-specific linear time trends capture gradual, country-specific innovation dynamics such as structural change, evolving R&D capacity, or domestic policy development. These specifications allow countries to follow distinct underlying paths of plastics-related innovation independent of the external policy shock. We address common global shocks and EU-wide developments, such as COVID-19, the European Green Deal, Brexit, and the 2020 oil price collapse, with additional controls.

5 Results

This section introduces the main results, cross-country heterogeneity in China ban exposure and heterogeneity in innovation types –process and product innovations– driven by the ban.

[7] https://time.com/5593314/malaysia-send-plastic-garbage-back/; urlhttps://www.cfr.org/in-brief/trash-trade-wars-southeast-asias-problem-worlds-waste

5.1 Main results

Our baseline regressions in Table 3 show no clear overall effect: when all plastics-related eco-innovation patents are pooled together, the Chinese waste-import ban does not appear to significantly increase aggregate patenting in Europe (column 1). But an unchanged aggregate can easily hide meaningful underlying dynamics. A shock that tightens a specific technological constraint is unlikely to expand total inventive output uniformly; instead, it typically reshapes how firms allocate R&D effort across technological domains and whether they rely on domestically generated inventions or the adoption of existing foreign technologies. For this reason, disaggregating patents into new inventions and technology transfers is essential for uncovering how the ban altered the direction – rather than the overall scale – of innovation.

Once we distinguish between new patents – capturing domestic inventive activity – and transfer patents – reflecting the adoption of existing foreign technologies – a very different pattern emerges (Columns 2 and 3). New plastics-related eco-innovations increase significantly after the ban, while transfers decline. Because transfer patents account for the majority of plastics-related filings, their contraction mechanically offsets the rise in new inventions, yielding the aggregate null effect in Column 1.

This divergence reflects a shift in the incentives facing European innovators. The abrupt tightening of end-of-life constraints increased the relative returns to technologies that mitigate, process, or valorize plastic waste, inducing firms to redirect R&D toward locally developed solutions. At the same time, foreign technologies developed under different regulatory and material conditions may have fit poorly with the new domestic constraints, reducing their attractiveness. The decline in transfers therefore signals not a reduction in innovative effort, but a reduced applicability of existing foreign technologies and a reorientation toward domestically adapted innovation.

The sole exception is triadic transfers – applications filed simultaneously in Europe, the United States, and Japan–, which increase markedly, indicating continued diffusion of only the highest-value existing technologies (Column 4). This increase suggests that, under tighter waste constraints, only high-value foreign technologies remained sufficiently productive to justify adoption. Lower-value or incremental foreign innovations became less relevant once domestic waste burdens increased. This selective diffusion is in line with a rising shadow cost of an environmental constraint inducing firms to adopt only high-performance solutions capable of fixing the new conditions.

In Table 4, we assess the robustness of these findings to a range of contemporaneous global and European shocks that could plausibly influence plastics-related innovation. These shocks are not absorbed by country-specific linear trends, which capture gradual dynamics rather than discrete global events. Across all specifications, the estimated effect of the China ban on new plastics-related eco-innovation remains positive, statistically significant, and similar in magnitude. The results are robust to accounting for European policy responses: restricting the post-ban window to 2018–2020 or including a dummy for subsequent EU regulation yields the same conclusions, indicating that the innovation response was already underway before later EU initiatives took effect.

To probe potential anticipation effects, we include indicators for the 2014 partial restrictions and for the 2017 announcement year. In both cases, the coefficient on the 2018 ban remains stable, while earlier restrictions do not generate comparable responses. This pattern reinforces the interpretation that the observed innovation response reflects the abrupt tightening of disposal constraints associated with the full ban, rather than gradual policy anticipation or contemporaneous global shocks.

5.2 Spillovers and placebo tests

To further assess whether the observed innovation response reflects a reallocation toward plastics-related eco-innovation rather than a general innovation shock, we examine outcomes beyond plastics-related eco-innovations. A policy shock that tightens an environmental constraint needs not only stimulate targeted innovation; it can also generate spillovers by altering the composition of inventive effort within the plastics domain and across the wider economy.

Table 5 we study four complementary outcomes: plastics innovations that are not environmentally oriented (columns 1–2), the share of plastics eco-innovations within all plastics patents (columns 3-4), patenting outside the plastics sector (columns 5-6), and the share of plastics eco-innovations within patents across all industries (columns 7-8). In these specifications, the dependent variables explicitly incorporate innovation activity beyond plastics-related eco-patents. We therefore omit the control for overall non-plastics patenting, which would mechanically overlap with the outcome and risk absorbing part of the variation of interest.

These outcomes provide a fuller picture of how a foreign environmental shock reshapes the allocation of inventive activity and also help strengthen identification. If the observed increase in eco-innovation were simply part of a general surge in patenting or driven by unrelated trends in

the plastics industry, we would expect to see similar patterns in non-eco plastics technologies or in sectors not directly exposed to the waste-management shock. The absence of such responses therefore constitutes a falsification test for alternative explanations. Conversely, if the ban genuinely redirected inventive effort toward environmentally oriented plastics technologies, we should observe a rising eco-share within plastics and a relative decline in patenting outside the plastics domain. Examining these spillovers therefore allows us to rule out competing interpretations and confirm that the ban shifted which technologies were pursued, not just the overall volume of innovation.

We find four patterns that clarify how the ban redirected the structure of innovation. First, plastics innovations outside the environmental domain do not exhibit a statistically significant response, indicating that the post-ban increase is not a broad upswing in plastics patenting. Second, the share of plastics patents that are environmentally oriented rises significantly for new patents, consistent with a reallocation of inventive effort within the plastics domain toward waste-management and substitution technologies most directly affected by the tightening of end-of-life constraints. Third, patenting outside the plastics sector declines, suggesting that innovative resources were reallocated toward addressing the newly binding waste-disposal constraint created by the ban rather than expanding inventive activity economy-wide. Finally, the share of plastics-related eco-innovations within patents across all industries increases significantly for both new and transfer patents, indicating that plastics eco-innovation becomes a more prominent component of overall inventive activity following the shock.

These spillover patterns strengthen identification by ruling out a general innovation upswing, a plastics-wide patenting boom, or unrelated sectoral trends as drivers of the results. The evidence instead points to a targeted reallocation of inventive effort toward plastics-related eco-innovations, precisely in the technological domains most affected by the tightening of end-of-life constraints.

5.3 Heterogeneity in exposure to the China ban

Having established that the China ban induced a targeted reallocation of inventive effort toward plastics-related eco-innovations, we next examine how the magnitude and composition of this response vary with countries' exposure to plastics production, consumption, and waste trade. Using the measures introduced in Sections 4.2 and 3.4, Table 6 reports estimates that allow the effect of the ban to differ systematically with pre-existing differences in waste exposure and domestic plastics flows. Across most specifications, a first-order result remains unchanged:

new eco-innovation patents increase after the ban, while transfers decline. The interaction terms reveal, however, that the magnitude and composition of this adjustment vary substantially across countries.

We begin with direct exposure to the China ban. Countries in the top quintile of pre-ban plastic waste exports to China exhibit markedly stronger responses on both margins (columns 1–2). These countries experienced the most abrupt increase in domestic waste-management pressure once Chinese processing capacity became unavailable. Consistent with this mechanism, new eco-innovations rise more strongly, while transfers fall more sharply than in less exposed countries. Notably, the interaction coefficients are similar in magnitude to the baseline post-ban effects, implying that for the most exposed countries the innovation response is effectively doubled. This scaling provides direct empirical validation of the mechanism: countries most dependent on China as an external waste outlet were forced to adjust technologically when that outlet disappeared.

We then examine heterogeneity along a complementary dimension: the ongoing scale of plastics circulating through domestic economies. Countries with higher levels of plastics production and consumption display amplified innovation responses following the ban (columns 3–4), but the two measures capture distinct exposure mechanisms. Plastics production reflects upstream industrial scale and exposure to the shock through global production and export linkages. When external disposal routes contracted, producers faced higher effective waste-related constraints via rejected shipments, tighter standards in export markets, and a reduced ability to externalize downstream waste. In the production specification, the baseline effect of the ban on new patents remains significant and the interaction term is positive, indicating that both smaller and larger producers are affected, with larger producers experiencing a stronger response of local inventive activity. This pattern suggests that the tightening of end-of-life constraints had economy-wide implications even for countries with modest production levels, while scale amplified the adjustment pressure.

Plastics consumption, by contrast, directly proxies for post-consumer waste generation. In this specification (columns 5–6), the baseline effect of the ban disappears and only the interaction with consumption is significant, indicating that the innovation response is concentrated in countries with large domestic consumption. This pattern is consistent with end-of-life constraints becoming binding primarily in countries with sufficiently large post-consumer waste volumes. In high-consumption countries, large quantities of plastics continued to enter the waste stream even as export options vanished, sharply increasing the returns to technologies that reduce waste, improve recyclability, or enable material substitution.

To further sharpen this distinction between production and consumption, we examine an interaction with the share of domestic plastics production that is exported (columns 7–8). Prior to the ban, export orientation is unrelated to innovation outcomes. This is intuitive: plastics waste arises primarily at the point of consumption, so exporting a large share of production effectively externalized the associated waste burden to foreign consumers and foreign waste-management systems. After the ban, however, the interaction becomes positive and significant for transfer patents only. This pattern suggests that export-oriented producers were indirectly exposed to the ban once their foreign customers could no longer manage plastics waste, creating pressure to adapt in order to preserve access to export markets. The fact that the response operates on the transfer margin is consistent with weaker pre-existing domestic capabilities in recycling or substitution technologies, leading these countries to rely more heavily on the adoption of existing foreign solutions rather than on new domestic inventions.

Table 7 shows that heterogeneity in the innovation response depends on countries' waste-disposal routes, distinguishing between total waste exports and flows directed specifically to the EU versus the Rest of the World (ROW). When exports are measured in value (odd columns), the post-ban effects mirror the baseline results: transfers decline significantly, while new patents increase. The interaction terms indicate that larger export flows amplify this response. Higher export values reflect continued reliance on waste-export markets following the ban – markets that had become more selective and more costly with the contraction of the principal low-quality outlet. The stronger interaction effects are therefore consistent with a cost-pressure mechanism that raises the relative returns to domestic innovations reducing reliance on these suddenly more expensive export routes.

When exposure is measured in physical quantities (even columns), the results display a different pattern. The baseline effect of the ban is no longer statistically distinguishable from zero. Instead, the positive and significant interaction term indicates that the innovation response is concentrated in country–years with larger exported waste volumes. This pattern indicates that the ban did not generate a general innovation response and rather points to a more localized material-constraint mechanism. Innovation increases only in country-years with larger exported waste volumes, where the tightening of foreign disposal outlets implies a more substantial physical displacement of waste and correspondingly stronger pressure on domestic treatment capacity.

The results suggest that the ban operated through both economic and material margins: export values reflect compositional upgrading and changing cost conditions in waste-export markets, whereas quantities isolate where the physical tightening of disposal capacity was suf-

ficiently severe to induce innovation. Importantly, aside from these interaction patterns, the core results of the paper remain robust to using quantity-based measures of exposure. The direction, magnitude, and statistical significance of the post-ban effects in all previous tables are unaffected, indicating that the overall findings do not hinge on how waste flows are measured.

Turning to destination-specific flows, the results show that the post-ban effect on new innovation emerges only when waste exports are directed toward the EU and is absent when exports are directed to the ROW. This asymmetry is economically meaningful. Redirecting waste within the EU does not provide access to a lax disposal margin; instead, it subjects exporters to comparatively stringent and coordinated environmental standards, thereby reinforcing rather than alleviating domestic disposal constraints. By contrast, exports to the ROW appear to function more as a substitute for the pre-ban Chinese disposal margin, providing access to comparatively less regulated outlets and partially mitigating domestic waste pressures rather than intensifying them.

5.4 Heterogeneity in innovation types

We next examine whether the China ban affected different types of plastics-related eco-innovations in distinct ways. Table 8 distinguishes between process innovations – which primarily concern recycling, chemical and mechanical recovery, and end-of-life treatment technologies – and product innovations, which involve redesigning plastics or developing new materials that are easier to recycle or generate less waste. This decomposition allows us to identify where along the plastics value chain the adjustment to the tightening of waste-management constraints was strongest.

Columns 1–4 reveal a clear asymmetry in the innovation response. Process innovations exhibit a markedly larger reaction to the China ban than product innovations. More than 90 percent of process patents in our sample relate to recycling and waste-treatment technologies, and the estimated effect of the ban is substantially larger for these downstream innovations. This pattern is consistent with the ban creating an immediate bottleneck at the waste-management stage, sharply increasing the returns to technologies that alleviate disposal constraints.

Product innovations also increase following the ban, though by less in relative terms. These upstream responses include new polymer formulations, biodegradable materials, and design changes that improve recyclability. While the relative effect is smaller than for process technologies, product innovations account for a larger share of total plastics-related patenting. As

a result, the absolute number of product-related eco-patents generated after the ban exceeds that of process patents, indicating a complementary adjustment in materials and product design alongside improvements in waste treatment. As in earlier results, the response across both innovation types is driven primarily by new domestic inventions rather than technology transfers, consistent with the need for locally adapted solutions following the tightening of end-of-life constraints.

Columns 5–8 focus on new patents and reveal further heterogeneity across innovation types. The increase in new patenting is substantially larger for process innovations than for product innovations: the baseline effect of the ban is more than three times larger for recycling and waste-treatment technologies than for product-related inventions. This confirms that downstream process innovation accounts for the core adjustment to the tightening of end-of-life constraints.

The heterogeneity specifications sharpen this distinction. While process innovations respond broadly to the China ban across countries, cross-country differences in exposure matter primarily for product innovations. Interaction terms with plastics production and waste-export dependence are positive and statistically significant for product patents, but not for process patents. This indicates that countries more exposed to the tightening of end-of-life constraints – whether through larger plastics markets or greater reliance on external disposal routes – adjusted disproportionately by innovating in materials and product design. In contrast, recycling and waste-treatment technologies responded more uniformly, reflecting a common downstream bottleneck faced by all countries once external disposal options contracted.

6 Robustness checks

This section assesses the robustness of our baseline findings to concerns related to common global shocks, measurement choices, patent classification, and estimation methods.

Table 9 reports a series of robustness checks examining how the baseline effect of the ban (Column 1) on new patents could be affected by our measurement choices or estimation method. We first verify that our findings are not driven by the value-weighting scheme. Column (2) reports estimates using unweighted patent counts and yields coefficients of similar sign and magnitude.

We observe a difference when changing the assignment of EPO patents. In the main analysis,

EPO patents are assigned to all EPO member states in the filing year. In Columns (3)–(4) of Table 9, we exclude EPO patents from national counts. When restricting the sample to new patents filed only through national patent offices (New No EP), the coefficient on the China ban becomes smaller and statistically insignificant. This contrast with the baseline indicates that the post-ban increase in new plastics-related eco-innovations is concentrated in patent applications involving the European Patent Office. Given that EPO filings are typically associated with higher expected value and broader applicability, this pattern suggests that the innovation response to the ban was driven primarily by inventions with wider technological or market relevance, rather than by an expansion of purely national filings.

For technology transfers, the contrast is even sharper. Excluding EP-assigned transfer patents (Column 4) reverses the baseline result: rather than declining, transfers increase significantly after the ban. This reversal indicates that the contraction in technology transfers documented in the baseline is driven almost entirely by EP-mediated transfers, which account for a large share of cross-border diffusion within Europe. Once EP patents are excluded, the remaining transfers – primarily those recorded at national patent offices – do not display the same negative response and instead show a modest increase. This pattern suggests that the channel through which the ban reduced technology transfers operates predominantly through EP filing routes.

In sum, the results excluding EP patents indicate that both the rise in new eco-innovations and the decline in transfers observed in the baseline are concentrated in patents filed via the European Patent Office, while filings recorded only at national offices respond much less. This is consistent with the interpretation that the China ban disproportionately affected innovation and diffusion channels associated with broader, multi-country patenting strategies, reshaping not only the direction of plastics-related eco-innovation but also the pathways through which technologies circulate within Europe.

Finally, we test whether results are driven by Germany, the largest plastics producer/exporter in our sample sample, but find that excluding Germany leaves the China ban coefficient similar to the baseline (Column 5). Re-estimating the model with Poisson pseudo-maximum likelihood (PPML) yields similar results (Column 6), confirming that our findings are not an artifact of the estimation method and are robust to alternative ways of handling count data and heteroskedasticity.

6.1 Alternative definitions of eco-innovation

Moreover, we subject our outcome measure to a wide range of alternative definitions of eco-innovation, including both reliance on existing patent classifications (Table 10) and progressively stricter textual criteria for keyword matching (Tables A11, A12, A14).

Results obtained using stricter textual criteria for keyword matching are reported in Tables A11, A12, and A14, with detailed explanations of these alternative rules provided in Appendix A. Across all of these specifications, the effect of the ban remains positive and significant for new patents and negative and significant for transfer patents, underscoring that our findings are not sensitive to the precise way in which plastics-related eco-innovations are identified.

We further assess the robustness of our findings by replacing the text-based identification of plastics-related eco-innovations with measures derived exclusively from CPC subclasses within the Y02 environmental domain. These classifications offer a more conservative definition of eco-innovation but are known to underrepresent several plastics-related technologies, particularly in recycling and substitution activities. We construct three measures of plastics-related eco-innovation. The broadest measure, All CPC-EI, includes both product and process innovations identified using the CPC codes Y02W 30/62, Y02W 90/10, Y02P 20/143, and Y02W 30/50. We then distinguish between CPC Product-EI, which corresponds to codes Y02W 90/10 and Y02P 20/143, and CPC Process-EI, identified using codes Y02W 30/62 and Y02W 30/50.

Table 10 reports estimates based on CPC classifications, which sometimes differ markedly from those obtained using the text-based indicators. For the aggregate CPC-based eco-innovation measure (Columns 1–2), the coefficient on the China ban is negative for new patents and close to zero for transfers, in contrast to the positive response of new eco-innovations identified in the baseline specification. Disaggregating CPC-based measures into product and process categories yields similarly mixed patterns: new CPC product patents increase after the ban, while CPC process innovations decline. Transfer patents also respond heterogeneously, with decreases in CPC product transfers and increases in CPC process transfers.

These divergent responses are consistent with the coverage patterns documented in Figure 6, and suggest that CPC subclasses capture only a limited and uneven subset of the innovation activity triggered by the ban. The figure shows that, in aggregate, CPC-based measures capture only a small share of the plastics-related eco-innovations identified through textual analysis, indicating that much of the relevant innovative activity falls outside the Y02 classification. Importantly, this overlap increases over time, particularly after 2018. While improving coverage

might appear reassuring, this evolving overlap poses a challenge for identification: time-varying measurement error can mechanically generate spurious dynamics in estimated treatment effects.

The disaggregated panels further highlight important asymmetries. As shown in Panel (c), CPC classifications perform particularly poorly for product-related eco-innovations, capturing only a few percent of the innovations identified by the text-based approach. This likely reflects the fact that CPC subclasses are concentrated in polymer and materials categories and do not systematically capture downstream product redesign, substitution, or application-level innovations. Panel (b) shows that process-related eco-innovations are better captured by CPC codes, but coverage is highly uneven over time, with sharp fluctuations around the ban period. This unevenness further complicates inference, as it makes CPC-based estimates sensitive to classification changes rather than underlying innovation responses.

These patterns underscore the value of a text-based identification strategy that consistently captures plastics-related eco-innovations across product and process domains and over time, and that better aligns with the technological adjustments induced by changes in waste-management constraints.

7 Conclusion

This paper examines how foreign environmental policies can reshape domestic innovation incentives by altering material conditions rather than regulatory rules. Using China's 2018 ban on plastic waste imports as a natural experiment, we study how an abrupt disruption to global waste trade affected plastics-related eco-innovation in Europe. By combining detailed patent data with novel measures of exposure to the ban, we trace how innovation responded across countries, technologies, and channels of diffusion.

We show that the ban acted as a powerful material-constraint shock that reshaped the direction of plastics-related innovation in Europe. While aggregate patenting in plastics eco-innovation does not increase, this null effect masks substantial compositional change. Disaggregating patents reveals a sharp rise in new domestic eco-innovations alongside a contraction in technology transfers, indicating that the ban altered not the scale but the nature of technological adjustment. Only the highest-value foreign technologies—captured by triadic transfers—continued to diffuse, suggesting that most existing solutions were ill-suited to the new waste-management constraints imposed by the loss of external disposal options.

The response to the ban varies systematically across countries. Innovation effects are strongest where adjustment pressures were greatest: in countries highly exposed to China as a waste outlet before 2018 and in countries with large, ongoing domestic plastics flows that had to be absorbed internally once exports collapsed. By contrast, countries that had previously externalized waste through exports of plastics products relied more heavily on foreign technologies after the ban, consistent with weaker pre-existing domestic capabilities. Spillover analyses further show that the ban redirected inventive effort toward plastics-related technologies at the expense of innovation elsewhere, confirming that the results reflect a reallocation of technological effort toward the newly binding constraint rather than a general innovation upswing.

Finally, decomposing innovation by type reveals that the strongest relative response occurred in downstream process innovations related to recycling and waste treatment, with a complementary but smaller adjustment in upstream product design and materials. Across all dimensions, the adjustment is driven primarily by new domestic inventions rather than by the diffusion of off-the-shelf foreign technologies. Taken together, these findings highlight how foreign environmental policies can induce domestic technological change by altering material conditions at home. More broadly, they underscore a novel channel of policy-induced innovation in which shocks originating in emerging economies reshape innovation trajectories in advanced economies by forcing the internalization of previously externalized environmental constraints.

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8 Figures

Figure 1: Share of China in world plastics imports (HS3915) - (Tran et al. 2021)

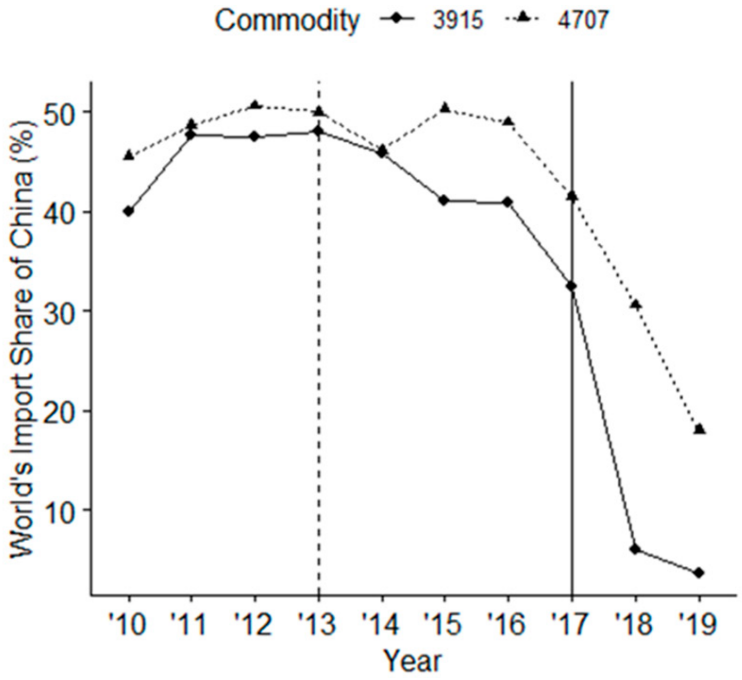
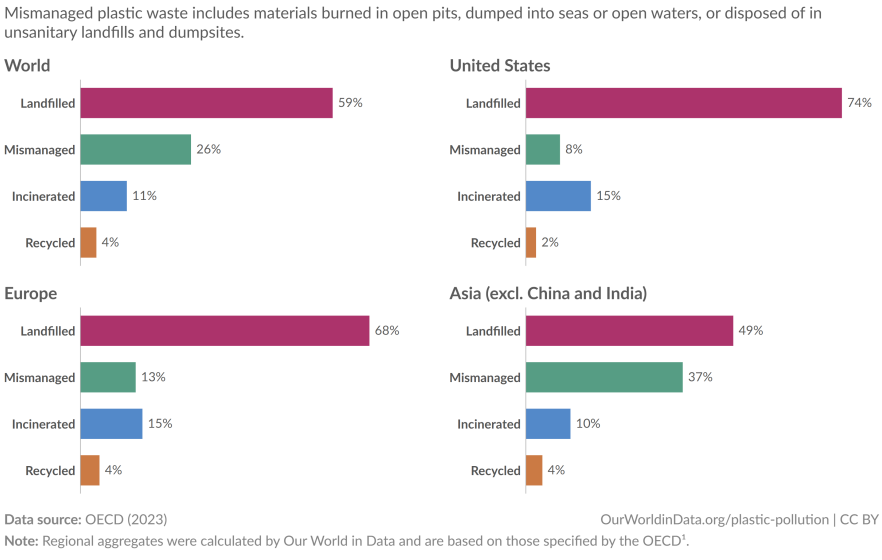
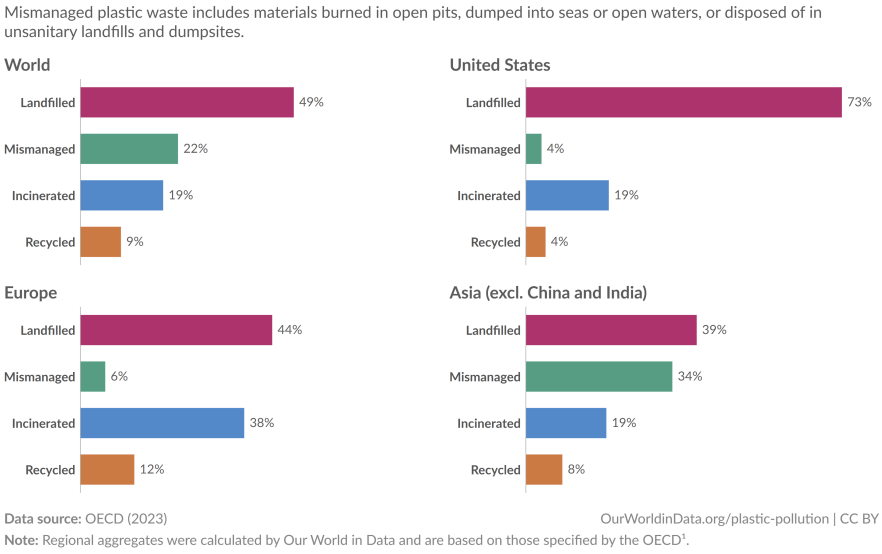


Figure 2: Share of plastic waste that is recycled, landfilled, incinerated and mismanaged, 2000 and 2019



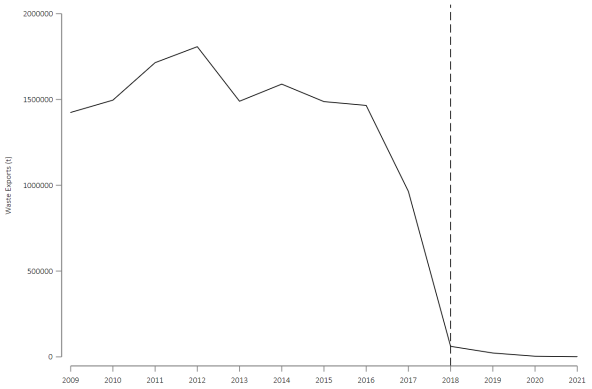
(a) 2000



(b) 2019

Figure 3: EU exports of plastics waste

(a) Quantity of exports to China



(b) Quantity of exports to EU and ROW

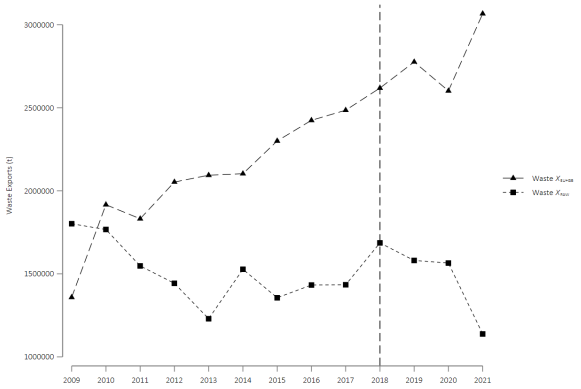


Figure 4: Unit price of plastic waste exports: yearly average

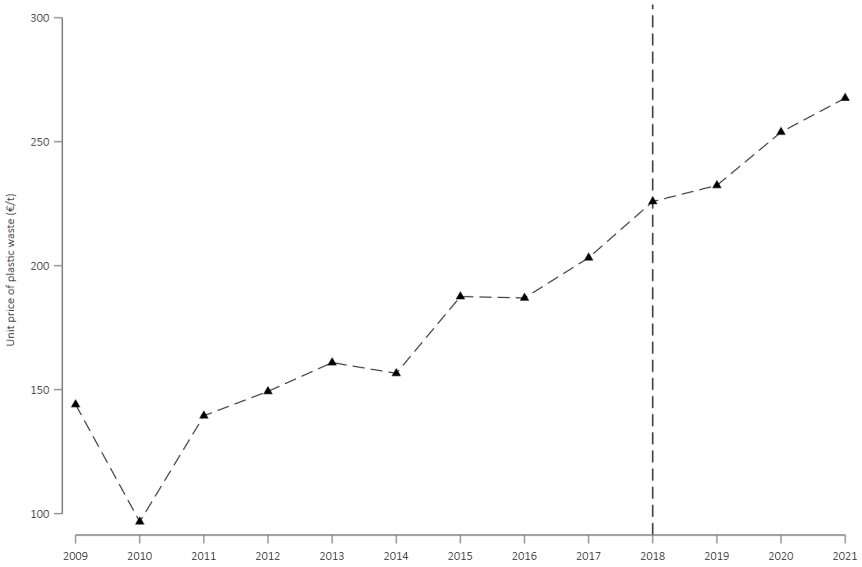


Figure 5: Textual analysis

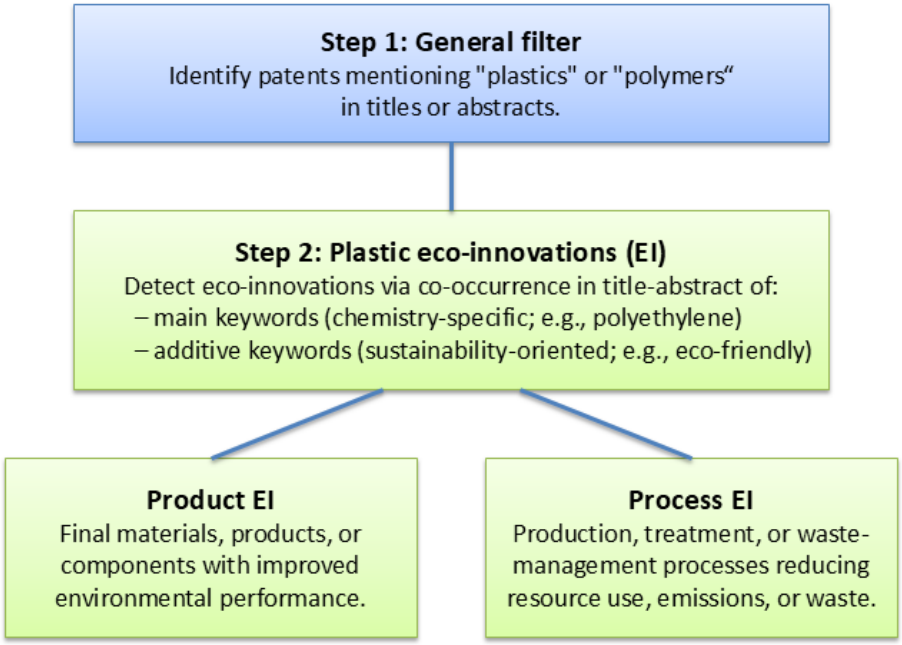
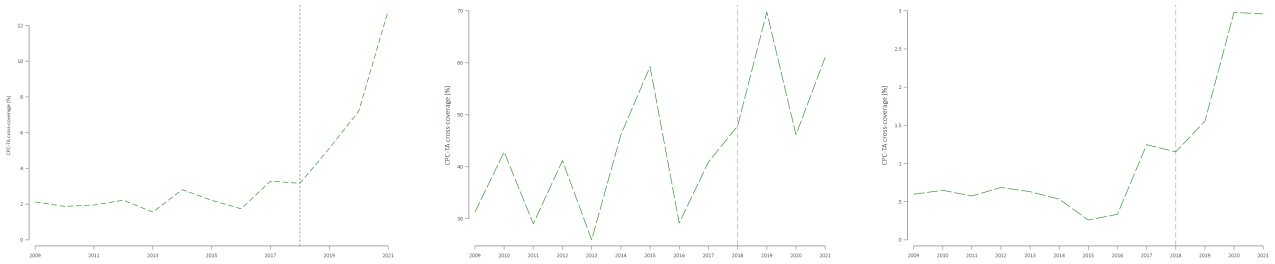


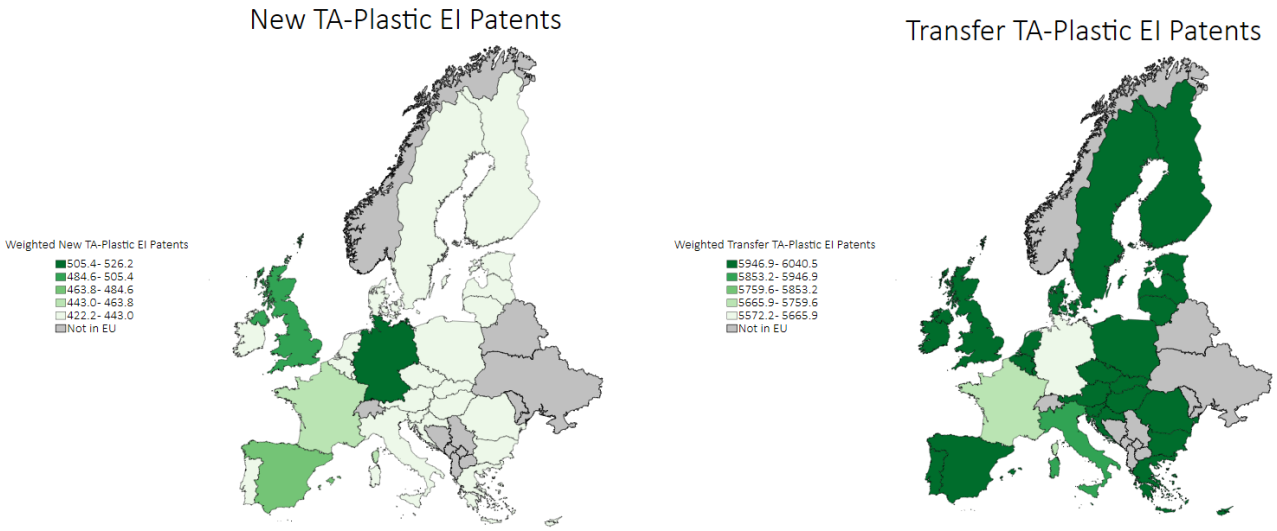
Figure 6: Share of plastics eco-innovation patents identified by the CPC method among those identified using textual analysis



(a) All plastics eco-innovations (b) Process eco-innovations (c) Product eco-innovations

Notes: The figure reports the share of patents identified as plastics-related eco-innovations using the textual analysis that would also be identified using CPC classifications. CPC subclasses used are Y02W 30/62 and Y02W 30/50 for process eco-innovations; Y02W 90/10 and Y02P 20/143 for product eco-innovations; and the union of these subclasses for the full sample.

Figure 7: Average annual weighted filings of patents in EU Member States and Great Britain, 2010-2021



(a) New

(b) Transfer

9 Tables

9.1 Descriptive statistics

Table 1: EI CPC-1digit

CPC 1digit	Nb.	%
A – Human necessities	54,356.0	10.1
B – Performing operations; transporting	182,078.0	33.9
C – Chemistry; metallurgy	187,053.0	34.9
D – Textiles; paper	20,630.0	3.8
E – Fixed constructions	11,711.0	2.2
F – Mechanical engineering; lighting; heating; weapons; blasting engines or pumps	18,011.0	3.4
G – Physics	12,703.0	2.4
H – Electricity	23,401.0	4.4
Y – General tagging of new technological developments and cross-sectional technologies	26,750.0	5.0
Total	536,693.0	100.0

Table 2: Descriptive Statistics: main variables. Weighted patents.

	Obs	Mean	Std. Dev.	Min	Max
EI	364	6,430.96	235.61	5,728.00	7130.00
New EI	364	433.10	77.02	323.00	817.00
Transfer EI	364	5,997.87	256.61	4,999.00	6,658.00
Triadic EI transfers	364	174.88	99.83	0.00	405.00
New Process EI	364	6.45	7.86	0.00	31.00
Transfer Process EI	364	98.40	92.03	34.00	428.00
New Product EI	364	420.21	79.59	298.00	812.00
Transfer Product EI	364	5,850.47	212.12	4,904.00	6,462.00
General excl. EI	364	1,044,920.01	103,562.35	799,876.00	1,381,712.00
Plastic waste exports in value (mil. €)					
Waste exports (total)	364	30.31	61.81	0	396.5
Waste X_{EU+GB}	364	13.57	25.98	1.00	178.42
Waste X_{RoW+CN}	364	18.73	39.99	1.00	276.08
Waste X_{RoW}	364	18.33	39.25	1.00	270.68
Waste X_{CN}	364	1.41	0.94	1.00	10.73
Plastic waste exports in quantity (t)					
Waste exports (total)	364	172,154.40	279,866.70	2,018.45	1,536,662.00
Waste X_{EU+GB}	364	81,394.39	111,039.20	0.004	587,433.10
Waste X_{RoW+CN}	364	90,759.97	194,943.10	0.567	1,184,227.00
Waste X_{RoW}	364	53,593.70	103,420.40	0.567	550,566.00
Waste X_{CN}	364	37,167.27	109,032.70	1.00	800,407.70
Plastics in value (mil. €)					
Exposure	364	2,1262.94	44,026.60	106.68	21,9834.25
Production	364	12,216.43	21,694.82	6.53	111,796.34
X/P	364	0.34	0.32	0.00	1.00
GDP	362	515747.07	785896.38	6287.60	3676460.00
Population	364	18187769.63	23115198.58	412477.00	83196078.00
Manufacturing VA	362	72304.10	123182.23	700.80	687379.00
Agriculture VA	362	7644.95	9755.50	68.90	36702.20

9.2 Results

Table 3: Main effects

	(1) EI plastics	(2) New	(3) Transfers	(4) Triadic transfers
China ban	-0.003	0.387***	-0.033***	0.476***
	(0.002)	(0.014)	(0.003)	(0.168)
Waste exports	0.020***	0.036	0.019***	-0.000
	(0.005)	(0.083)	(0.007)	(0.104)
General excl. EI	-0.177***	1.610***	-0.297***	-0.102
	(0.009)	(0.082)	(0.013)	(0.098)
Observations	362	362	362	362

Regressions include country fixed effects, a country-specific linear time trend, and control variables: GDP, population, sectoral composition, overall patenting trend, and waste exports. Standard errors in parentheses are clustered at the country level. Significance level: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Anticipation and global common shocks

	(1) Pre-EU reg	(2) Partial ban	(3) Anticipated ban	(4) EU reg	(5) Post-2020	(6) Paris Ag.	(7) Euro crisis	(8) Oil crisis	(9) Brexit announce
Ban	0.327***	0.351***	0.387***	0.387***	0.341***	0.379***	0.382***	0.414***	0.385***
	(0.016)	(0.014)	(0.021)	(0.014)	(0.011)	(0.013)	(0.014)	(0.015)	(0.013)
Partial ban 2014		-0.115***							
		(0.012)							
Anticipated ban 2017			0.000						
			(0.014)						
EU single use				0.003					
				(0.008)					
Post-2020					-0.281***				
					(0.017)				
Paris Agreement						0.065***			
						(0.016)			
Euro crisis							0.024***		
							(0.008)		
Oil shock								-0.112***	
								(0.011)	
Brexit announcement									0.100***
									(0.012)
Waste exports	0.047	0.029	0.036	0.036	0.036	0.040	0.030	0.039	0.041
	(0.089)	(0.082)	(0.083)	(0.083)	(0.083)	(0.080)	(0.086)	(0.087)	(0.077)
General excl. EI	1.144***	1.718***	1.610***	1.617***	0.637***	1.603***	1.581***	1.568***	1.600***
	(0.117)	(0.075)	(0.084)	(0.083)	(0.106)	(0.081)	(0.085)	(0.079)	(0.082)
Observations	335	362	362	362	362	362	362	362	362

Regressions include country fixed effects, a country-specific linear time trend, and control variables. Controls include GDP, population, sectoral composition, overall patenting trend, and waste exports. Standard errors are clustered at the country level. Standard errors in parentheses. Significance level: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Spillovers

	Plastics excl. EI		EI/Plastics		General excl. EI		EI/General	
	(1) New	(2) Transfers	(3) New	(4) Transfers	(5) New	(6) Transfers	(7) New	(8) Transfers
China ban	0.003	0.001	0.028***	0.001	-0.098***	-0.133***	0.001***	0.001***
	(0.030)	(0.004)	(0.003)	(0.001)	(0.029)	(0.010)	(0.000)	(0.000)
Waste exports	0.111	0.025	0.003	-0.004	0.149	0.049	-0.000	-0.000
	(0.075)	(0.027)	(0.010)	(0.006)	(0.110)	(0.037)	(0.000)	(0.000)
Observations	362	362	362	362	362	362	362	362

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Heterogeneity Related to the Plastics Industry

	Exposure		Production		Consumption		X/P	
	(1) New	(2) Transfer	(3) New	(4) Transfer	(5) New	(6) Transfer	(7) New	(8) Transfer
Ban	0.373***	-0.031***	0.200**	-0.004	0.120	-0.002	0.353***	-0.020***
	(0.016)	(0.003)	(0.074)	(0.011)	(0.106)	(0.015)	(0.028)	(0.006)
Exposure	0.000	0.000						
	(.)	(.)						
Ban × Exposure	0.408***	-0.050***						
	(0.015)	(0.004)						
Production			0.012	0.003				
			(0.038)	(0.007)				
Ban × Production			0.025**	-0.004***				
			(0.010)	(0.001)				
Consumption					-0.004	0.009		
					(0.042)	(0.007)		
Ban × Consumption					0.034**	-0.004**		
					(0.013)	(0.002)		
X/P							0.051	-0.010
							(0.035)	(0.007)
Ban × X/P							-0.020	0.008**
							(0.018)	(0.004)
Waste exports	0.040	0.019**	0.051	0.017**	0.060	0.017**	0.034	0.020***
	(0.086)	(0.007)	(0.083)	(0.007)	(0.085)	(0.007)	(0.081)	(0.006)
General excl. EI	1.612***	-0.298***	1.621***	-0.300***	1.604***	-0.306***	1.597***	-0.295***
	(0.084)	(0.013)	(0.081)	(0.013)	(0.090)	(0.015)	(0.085)	(0.013)
Observations	362	362	362	362	362	362	362	362

Regressions include country fixed effects, a country-specific linear time trend, and control variables: GDP, population, sectoral composition, overall patenting trend, and waste exports. Standard errors in parentheses are clustered at the country level. Significance level: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Heterogeneity by waste export destination and measurement

	Transfer		New					
	Total		Total		EU		RoW+CN	
	Value (1)	Quantity (2)	Value (3)	Quantity (4)	Value (5)	Quantity (6)	Value (7)	Quantity (8)
Ban	-0.021***	0.043	0.327***	-0.077	0.331***	-0.060	0.345***	0.206
	(0.004)	(0.031)	(0.031)	(0.224)	(0.030)	(0.188)	(0.024)	(0.141)
Waste exports	0.016**	-0.004	0.055	0.020				
	(0.007)	(0.005)	(0.087)	(0.04)				
Ban × Waste exports	-0.006***	-0.007**	0.029**	0.042**				
	(0.002)	(0.003)	(0.014)	(0.020)				
Waste Exports$_{EU}$					0.003	0.000		
					(0.022)	(0.012)		
Ban × Waste Exports$_{EU}$					0.031**	0.042**		
					(0.014)	(0.018)		
Waste Exports$_{RoW+CN}$							-0.022	0.001
							(0.020)	(0.015)
Ban × Waste Exports$_{RoW+CN}$							0.024	0.019
							(0.013)	(0.014)
General excl. EI	-0.302***	-0.294***	1.633***	1.624***	1.635***	1.646***	1.644***	1.602***
	(0.014)	(0.013)	(0.081)	(0.076)	(0.082)	(0.078)	(0.077)	(0.087)
Observations	362	362	362	362	362	362	362	362

Note. Waste export exposure is measured alternatively in value and quantity. Quantity measures are expressed in metric tons and constructed from BACI bilateral trade data using HS codes 391510, 391520, 391530, and 391590, which identify plastic waste flows. Value measures are expressed in million euros and derived from EXIOBASE using product code p.90.1c for plastic waste. Destination groups are defined consistently across both data sources. The group EU includes all European Union member states and the Great Britain. The group RoW includes all non-EU importers excluding China, whereas RoW+CN captures exports to the rest of the world including China. All regressions include country and year fixed effects as well as controls. Significance level: ** $p < 0.05$, *** $p < 0.01$.

Table 8: Process and Product eco-innovations

	Baseline				Heterogeneity			
	Transfers		New		New x Production		New x Waste exports	
	Process	Product	Process	Product	Process	Product	Process	Product
Ban	-0.237***	-0.011***	1.169***	0.376***	1.076***	0.163*	1.165***	0.303***
	(0.032)	(0.003)	(0.035)	(0.016)	(0.165)	(0.083)	(0.063)	(0.035)
Ban × Production					0.013	0.028**		
					(0.021)	(0.010)		
Ban × Waste exports							0.002	0.035**
							(0.025)	(0.015)
Production					-0.064	0.014		
					(0.206)	(0.040)		
Waste exports	0.112	0.021***	0.031	0.034	0.042	0.050	0.032	0.056
	(0.258)	(0.006)	(0.150)	(0.085)	(0.158)	(0.085)	(0.158)	(0.089)
General excl. EI	-5.874***	-0.066***	1.539***	1.799***	1.563***	1.811***	1.541***	1.826***
	(0.146)	(0.014)	(0.251)	(0.089)	(0.246)	(0.088)	(0.255)	(0.089)
Observations	362	362	362	362	362	362	362	362

Regressions include country fixed effects, a country-specific linear time trend, and control variables. Controls include GDP, population, sectoral composition, overall patenting trend, and waste exports - except in (7) and (8). In columns (1)–(6), waste exports enter as a standard control variable. In columns (7)–(8), waste exports are interacted with the China ban to capture heterogeneity by pre-ban exposure to waste-export dependence. In these specifications, the coefficient on waste exports reflects the baseline (pre-ban) association, while the interaction term captures the differential post-ban effect.Standard errors are clustered at the country level. Standard errors in parentheses. Significance level: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

9.3 Robustness

Table 9: Robustness of patent measure

	(1) Baseline	(2) Unweighted	(3) New No EP	(4) Transfer No EP	(5) Excl. DEU	(6) PPML
Ban	0.387***	0.356***	0.014	0.315**	0.382***	0.064***
	(0.014)	(0.030)	(0.154)	(0.137)	(0.014)	(0.003)
Waste exports	0.036	0.025	0.017	-0.017	0.031	0.006
	(0.083)	(0.100)	(0.266)	(0.193)	(0.083)	(0.012)
General excl. EI	1.610***		-1.535**	0.129	1.667***	0.266***
	(0.082)		(0.586)	(0.363)	(0.064)	(0.015)
Observations	362	362	362	362	349	362

Dependent variables: EI-plastic new patents weighted in (1), (5-8); (2) EI-plastic new patents unweighted, (3) EI-plastic new patents not registered at EP, (4) EI-plastic transfer patents not registered at EP. Regressions include country fixed effects, a country-specific linear time trend, and control variables. Controls include GDP, population, sectoral composition, overall patenting trend, and waste exports. Standard errors are clustered at the country level. Standard errors in parentheses. Significance level: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 10: Comparative results with CPC-EI

	Total		Product		Process	
	(1) New	(2) Transfer	(3) New	(4) Transfer	(5) New	(6) Transfer
Ban	-0.290***	-0.048***	1.022***	-0.061**	-0.460***	0.059***
	(0.026)	(0.017)	(0.092)	(0.026)	(0.043)	(0.017)
Waste exports	-0.196	0.017	-0.118	-0.203	-0.018	0.073
	(0.159)	(0.083)	(0.334)	(0.137)	(0.147)	(0.079)
General excl. EI	-4.387***	-5.008***	-1.011**	-4.303***	-5.943***	-4.973***
	(0.162)	(0.107)	(0.418)	(0.123)	(0.217)	(0.112)
Observations	362	362	362	362	362	362

A Plastics-related patents: robustness

To verify that our results are not driven by specific choices in the textual identification of plastics-related eco-innovations, we re-estimate the baseline model using a series of increasingly stringent patent-selection rules for new and transfer weighted patents identified as product and process eco-innovations.

Specifically, these robustness checks target four dimensions of textual intensity: (i) the share of keywords in the abstract; (ii) the number of additive environmental-oriented keywords; (iii) the frequency of keyword occurrences and (iv) the recycling dimension.

First (i), we impose thresholds requiring that main and additive keywords jointly represent at least 0.5% and 0.75% of all words in the title and abstract (Tab. A11). These filters ensure that the identified patents contain a sufficient and relevant density of plastics-related and environmental-oriented terminology to capture eco-innovations and not only innovations. Second (ii), we require patents to include more than one, and separately more than three, additive keywords in order to capture patents where the environmental dimension is substantively present rather than incidental (Table A12).

Third (iii), we impose frequency-based selection rules that retain only patents in which additive keywords occur more than five or more than ten times in the title and abstract. We compute the total number of occurrences of additive keywords separately for process innovations and for product innovations by counting every occurence of multi-word expressions and their plural forms. We then retain only patents in which additive keywords appear frequently in the text, requiring more than five occurrences and, in a stricter version, more than ten occurrences, (x_1), of such keywords in the title and abstract (Table A13).

Finally (iv), we apply two domain-specific restrictions that retain only patents mentioning recycling either in the combination of the title and abstract (col. 1-3) or in the title only (col. 4-6), which isolates the subset of recycling process innovations. Results are reported in Table A14.

Table A11: Textual analyses and patents selection: share of keywords

	Product				Process			
	Keywords 0.5%		Keywords 0.75%		Keywords 0.5%		Keywords 0.75%	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	New	Transfer	New	Transfer	New	Transfer	New	Transfer
Ban	0.368***	-0.020***	0.353***	-0.021***	0.675***	-0.356***	0.675***	-0.358***
	(0.016)	(0.003)	(0.016)	(0.003)	(0.081)	(0.023)	(0.081)	(0.024)
Waste exports	0.022	0.019***	0.028	0.020***	0.235	0.022	0.235	0.021
	(0.079)	(0.006)	(0.080)	(0.005)	(0.227)	(0.142)	(0.227)	(0.143)
General excl. EI	1.584***	-0.131***	1.556***	-0.132***	-0.708**	-5.811***	-0.708**	-5.735***
	(0.114)	(0.014)	(0.115)	(0.014)	(0.309)	(0.128)	(0.309)	(0.129)
Observations	362	362	362	362	362	362	362	362

Table A12: Textual analyses and patents selection: number of keywords

	Product				Process			
	$AK > 1$		$AK > 3$		$AK > 1$		$AK > 3$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	New	Transfer	New	Transfer	New	Transfer	New	Transfer
Ban	0.529***	-0.087***	1.741***	-0.291***	0.383***	-0.033***	0.377***	-0.030***
	(0.017)	(0.004)	(0.035)	(0.007)	(0.016)	(0.003)	(0.016)	(0.003)
Waste exports	0.012	0.036**	-0.198	-0.025	0.025	0.019***	0.024	0.019***
	(0.102)	(0.017)	(0.223)	(0.026)	(0.081)	(0.007)	(0.081)	(0.005)
General excl. EI	1.245***	-0.947***	3.078***	-2.558***	1.530***	-0.296***	1.640***	-0.222***
	(0.111)	(0.025)	(0.205)	(0.053)	(0.113)	(0.013)	(0.114)	(0.013)
Observations	362	362	362	362	362	362	362	362

Table A13: Textual analyses and patents selection: occurence of keywords

	Product				Process			
	Occ. $x1 > 5$		Occ. $x1 > 10$		Occ. $x1 > 5$		Occ. $x1 > 10$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	New	Transfer	New	Transfer	New	Transfer	New	Transfer
Ban	0.889***	-0.029***	0.925***	0.081***	0.219**	-0.585***	-0.402***	0.305***
	(0.013)	(0.005)	(0.039)	(0.008)	(0.086)	(0.029)	(0.070)	(0.043)
Waste exports	-0.081	0.047**	0.043	0.036	0.233	0.052	0.057	0.364*
	(0.065)	(0.020)	(0.158)	(0.042)	(0.187)	(0.148)	(0.184)	(0.190)
General excl. EI	1.792***	-0.836***	1.311***	-1.446***	-0.945***	-5.188***	-2.869***	-2.486***
	(0.125)	(0.027)	(0.228)	(0.035)	(0.333)	(0.144)	(0.242)	(0.184)
Observations	362	362	362	362	362	362	362	362

Table A14: Textual analyses and patents selection: recycling technologies

	TA			Title		
	(1)	(2)	(3)	(4)	(5)	(6)
	Tot.	New	Transfer	Tot.	New	Transfer
Ban	-0.256***	0.705***	-0.356***	0.023	0.999***	-0.138***
	(0.026)	(0.085)	(0.023)	(0.032)	(0.095)	(0.031)
Waste exports	0.037	0.239	0.022	0.126	0.192	0.107
	(0.144)	(0.223)	(0.142)	(0.149)	(0.236)	(0.156)
General excl. EI	-5.495***	-0.755**	-5.811***	-5.794***	1.825***	-6.536***
	(0.122)	(0.319)	(0.128)	(0.132)	(0.397)	(0.148)
Observations	362	362	362	362	362	362

B Examples and Illustrations

Table A15: Examples of main and additive keywords for product and process eco-innovations

	Main keywords	**Additive keywords**
Product innovations	Biodegradable plastic	compostable
	PLA (polylactic acid)	bio-based
	PHA (polyhydroxyalkanoate)	recyclable
	Bio-sourced polymer	circularity
	Biobased packaging material	emission reduction
Process innovations	Mechanical recycling	depolymerization
	Chemical recycling	glycolysis
	Plastic-to-plastic conversion	contaminant separation
	Sorting and separation process	energy-efficient
	Advanced recycling process	super-critical CO_2

Table A16: Selected examples of product and process eco-innovations in plastics

Appln id	**Abstract (excerpt)**	**Interpretation**
Product eco-innovations		
57062	"...a stretched poly(arylene thioether-ketone) film made of a thermoplastic material ... having a melting point of 310–380 deg C ... and a reduced viscosity of 0.3–2 d l/g ... Its production process is also disclosed."	This invention develops a high-performance polymer film that achieves required mechanical properties at substantially reduced thickness. The environmental relevance arises from the design of a final material that uses less polymer mass per unit function. Because the improvement concerns the characteristics and structure of the end product itself, this is classified as a product eco-innovation.
103159	"...tools ... formed from thin plastic films. The films have a small thickness (preferably 5 to 50 μm) ... The softness and thinness of the plastic reduce risk of sample damage ... The plastic can also be treated ..."	The invention introduces ultra-thin plastic film tools designed to provide the same functionality with very low material intensity. The environmental benefit derives from reducing the quantity of polymer required for each manufactured item. As the innovation modifies the physical configuration and performance of the final object, it is categorized as a product eco-innovation.
Process eco-innovations		
5586	"...the polymer is re-precipitated in a general solvent by an easy method, and the used iron complexes are recovered in the solvent, thereby recycling the iron complexes."	This invention improves the polymer synthesis workflow by introducing a method that allows recovery and reuse of catalyst complexes and solvents. The environmental significance stems from reducing input requirements and waste during processing. As the claimed advances modify operational stages of the production chain rather than the product itself, this is classified as a process eco-innovation.
56243	"...oxygen-scavenging polymer compositions having high transparency and low haze ...the small difference in refractive indices enable the incorporation of regrind into the polymer composition to produce transparent shaped articles ... useful for sheeting, films, bottles, preforms and profiles."	The invention adapts processing conditions such that regrind can be incorporated into transparent polymer compositions without degrading optical performance. The environmental relevance lies in enabling the use of secondary materials in manufacturing. Because the innovation concerns the transformation process and its conditions rather than the intrinsic design of the final product, it is classified as a process eco-innovation.

Table A17: Selected examples of product and process eco-innovations in plastics (tabularx format)

Appln id	**Abstract (excerpt)**	**Interpretation**
Product eco-innovations		
57062	"...a stretched poly(arylene thioether-ketone) film made of a thermoplastic material ...having a melting point of 310–380 deg C ...and a reduced viscosity of 0.3–2 d l/g ...Its production process is also disclosed."	This invention develops a high-performance polymer film that achieves required mechanical properties at substantially reduced thickness. The environmental relevance arises from the design of a final material that uses less polymer mass per unit function. Because the improvement concerns the characteristics and structure of the end product itself, this is classified as a product eco-innovation.
103159	"...tools ...formed from thin plastic films. The films have a small thickness (preferably 5 to 50 μm) ...The softness and thinness of the plastic reduce risk of sample damage ...The plastic can also be treated ..."	The invention introduces ultra-thin plastic film tools designed to provide the same functionality with very low material intensity. The environmental benefit derives from reducing the quantity of polymer required for each manufactured item. As the innovation modifies the physical configuration and performance of the final object, it is categorized as a product eco-innovation.
Process eco-innovations		
5586	"...the polymer is re-precipitated in a general solvent by an easy method, and the used iron complexes are recovered in the solvent, thereby recycling the iron complexes."	This invention improves the polymer synthesis workflow by introducing a method that allows recovery and reuse of catalyst complexes and solvents. The environmental significance stems from reducing input requirements and waste during processing. As the claimed advances modify operational stages of the production chain rather than the product itself, this is classified as a process eco-innovation.
56243	"...oxygen-scavenging polymer compositions having high transparency and low haze ...the small difference in refractive indices enable the incorporation of regrind into the polymer composition to produce transparent shaped articles ...useful for sheeting, films, bottles, preforms and profiles."	The invention adapts processing conditions such that regrind can be incorporated into transparent polymer compositions without degrading optical performance. The environmental relevance lies in enabling the use of secondary materials in manufacturing. Because the innovation concerns the transformation process and its conditions rather than the intrinsic design of the final product, it is classified as a process eco-innovation.

Table A18: Patents captured by CPC plastics eco-innovation classes but not identified as plastics eco-innovations by textual analysis (false positives) – Part I

Appln ID	ISO2	Year	Title / abstract	CPC codes	AI explanation	AI on why not plastics EI
56854287	GB	2009	Groyne structure made from compressed tyre bales used as coastal or marine infrastructure.	Y02W 30/62	Civil engineering application reusing whole tyres as construction ballast and erosion protection.	Captured by CPC due to use of waste tyres, but the invention concerns infrastructure reuse rather than plastics recycling or plastics eco-innovation.
57150605	GB	2009	Baler for vehicle tyres used to form artificial reefs from compressed tyre bales.	Y02W 30/62	Mechanical device for compressing tyres for use as artificial marine structures.	Classified as waste management due to tyre reuse, but does not involve plastics material innovation or recycling processes.
57428551	EP	2009	Artificial grass granulated infill made from synthetic resin with controlled hardness and void structure.	Y02W 30/62	Manufacturing of artificial turf infill material for sports surfaces.	Captured due to synthetic resin use, but relates to product performance rather than plastics eco-innovation or waste reduction.
57936310	EP	2009	Vehicle part with sound insulation made from crumb rubber and binding material.	Y02W 30/62	Use of rubber-based insulation material for automotive noise reduction.	Captured due to secondary material use, but the invention targets cost and performance, not plastics environmental innovation.
267229417	FR	2009	Air-flow separation column device for handling filler-loaded air streams.	Y02W 30/62	Generic separation apparatus for industrial materials.	Captured due to broad waste-processing interpretation, but not specific to plastics, recycling, or environmental benefit.
267543203	EP	2009	Receiving-heating unit for bottles with mechanical and safety locking mechanisms.	Y02W 30/62	Mechanical device for handling and heating containers.	Captured under waste handling CPC class, but no plastics recycling or eco-innovation intent is present.
273301360	EP	2009	Wave energy-dissipating shore protection system using net and leaf structures.	Y02W 30/62	Coastal engineering solution for wave energy dissipation.	Incorrectly captured due to structural material interpretation; unrelated to plastics or waste management innovation.
273450049	EP	2009	Machine for compacting annular flexible materials using swage plates.	Y02W 30/62	General-purpose compaction machinery for flexible materials.	Captured by CPC due to waste handling overlap, but lacks plastics-specific or environmental innovation content.
274195914	EP	2009	Method for recycling used clothes and domestic textiles into pressed resin products.	Y02W 30/62	Textile recycling process producing composite pressed products.	Captured due to recycling classification, but the core invention concerns textiles rather than plastics eco-innovation.

Table A19: Patents captured by CPC plastics eco-innovation classes but not identified as plastics eco-innovations by textual analysis (false positives) – Part II

Appln ID	ISO2	Year	Title / abstract	CPC codes	AI explanation	AI on why not plastics EI
315410891	GB	2010	Tyre cutting machinery for reducing used tyres for storage and reuse.	Y02W 30/62	Mechanical equipment for cutting tyres to reduce volume and improve handling.	Captured because of waste tyre handling, but no plastics recycling or materials innovation is involved.
323419003	EP	2010	Method for recycling paper machine linings such as forming screens and press felts.	Y02W 30/62	Recycling process for industrial paper machine components.	Captured under waste management CPC classes, but the invention concerns industrial textiles, not plastics.
328466983	EP	2010	Solvent systems for foam nozzle cleaning with no flash point.	Y02W 30/62	Chemical formulation for equipment cleaning and safety.	Captured due to broad CPC scope, but unrelated to plastics, waste, or eco-innovation.
332431697	EP	2010	Device for stripping rubber gum from steel cords in conveyor belts.	Y02W 30/62	Industrial maintenance equipment for conveyor belt refurbishment.	Captured due to rubber processing, but lacks plastics recycling or environmental innovation intent.
381364910	ES	2011	Process for producing linear monoalkylbenzenes from polyethylene cracking residues.	Y02W 30/62	Chemical process converting plastic-derived hydrocarbons into detergent feedstocks.	Captured due to plastic-derived input, but functions as petrochemical substitution rather than plastics eco-innovation.
540248888	SK	2019	Device for producing building blocks from crushed waste containing thermoplastics.	Y02W 30/62	Manufacturing equipment for construction materials incorporating waste plastics.	Captured because of plastic content, but focuses on construction manufacturing rather than plastics system innovation.
559037962	EP	2021	Laminated panel structure for floors, ceilings, or walls.	Y02W 30/62	Building panel design focused on structural layering.	Captured due to material composition, but unrelated to plastics recycling or environmental innovation.
562319521	EP	2021	Genetic algorithm-based selection of spectroscopic light sources.	Y02W 30/62	Data-processing and optimization technique for spectroscopy.	Incorrectly captured; no connection to plastics, waste, or eco-innovation.
507058286	GB	2018	Cosmetic agent for temporary shaping of keratinic fibres using starch-based formulations.	Y02W 90/10	Cosmetic formulation using natural starches.	Captured under environmental CPC class despite no link to plastics, waste, or recycling innovation.

Table A20: Plastics eco-innovations identified by textual analysis but not captured by CPC classification (false negatives) – Part I

Appln ID	ISO2	Year	Title / abstract	CPC	AI explanation	AI on why not captured by CPC
594848444	SE	2021	A packaging material comprising a polymer coating designed to improve performance and recyclability of the packaging material.	D21H, B32B, C08F, C09D, B65D, B29C	Packaging material comprising a polymer coating designed to improve recyclability and compatibility with existing plastic recycling streams.	Primarily classified under packaging, paper, and coating CPC classes, where plastics are treated as ancillary materials rather than the object of environmental improvement.
547240855	EP	2020	Laminated film, and production method therefor, providing functional performance while addressing recyclability considerations.	C09D, B65D, B32B, C08J, C08K, B29D, C09J	Laminated plastic film designed to maintain functional performance while enabling improved recyclability of multilayer plastic packaging.	Classified as film and coating technology.
335743901	EP	2011	Magnetically enhanced recycling of plastics through improved separation and sorting processes.	B03C, Y01T, B07C	Recycling process for plastics using magnetically enhanced separation to improve sorting efficiency and recovery of plastic materials.	Classified under generic separation and sorting CPC classes, obscuring plastics-specific recycling and eco-innovation objectives.
597383489	EP	2020	A device for compression of emptied containers to facilitate handling, storage, and recycling.	B02C, B30B	Device for compressing emptied plastic containers to reduce volume and improve efficiency of plastic waste collection and recycling systems.	Classified as mechanical size-reduction equipment; system-level contribution to plastics recycling infrastructure is not reflected in CPC eco-innovation classes.
594327575	FI	2021	Polymer foam, methods and use related thereto, with improved material efficiency and performance.	C08J, C08L	Polymer foam material and related methods designed with improved material efficiency and reduced environmental impact in use.	Classified under polymer foam or materials engineering CPC classes, where environmental intent related to plastics is not explicitly captured.
580921225	EP	2021	All-plastic continuous spray trigger sprayer designed to improve recyclability by eliminating non-plastic components.	B05B	Mono-material plastic spray trigger sprayer designed to improve recyclability by avoiding metal or mixed-material parts.	Classified as consumer product or dispensing device technology.
497605641	ES	2017	Polymeric membrane material designed for environmentally oriented applications.	D01F, D04H, C01B	Polymeric membrane or material designed for environmentally oriented applications with explicit sustainability objectives.	Classified as membrane or materials technology.
496108782	EP	2017	Porous microparticles of biodegradable polymer and related methods of production and use.	A61K, A61L, C08J, B01J, C08L	Biodegradable polymer material designed to reduce long-term environmental persistence of plastic-based products.	Classified under biomedical or materials science CPC classes, where biodegradable plastics are not systematically tagged as eco-innovation.

Table A21: Plastics eco-innovations identified by textual analysis but not captured by CPC classification (false negatives) - Part II

Appln ID	**ISO2**	**Year**	**Title / abstract**	**CPC**	**AI explanation**	**AI on why not captured by CPC**
535843246	EP	2020	Recycling of superabsorbent polymer via UV irradiation in a flow system, wherein poly(acrylic acid)-based superabsorbent polymer is converted into poly(acrylic acid) with low total energy input.	C08J, C08L, B01J	Low-energy chemical recycling process that degrades superabsorbent polymer waste, commonly used in hygiene products, into reusable polymer material suitable for further applications.	Classified under polymer modification and chemical processing CPC classes.
489521581	EP	2018	Conversion of waste plastic through pyrolysis to produce high-value aromatic products such as benzene and xylenes via integrated hydroprocessing and separation steps.	C07C, B09B, B01J, C10B, C10G	Chemical recycling process that converts plastic waste into valuable petrochemical feedstocks, providing an alternative to virgin fossil-based inputs while addressing plastic waste accumulation.	Classified under chemical processing, refining, and waste treatment CPC classes.
500307027	ES	2017	Disposable glove for bodily hygiene, constituted as a mitten made of plastic material or cellulose, incorporating a cleaning wipe and a closure mechanism allowing the glove to be inverted and sealed after use.	A47K	Single-use plastic hygiene product designed to improve sanitary handling and containment of waste during personal care activities, with implications for downstream plastic waste generation.	Classified under hygiene and sanitary equipment CPC classes.