The Substitution Illusion: Product Bans and Packaging Waste
Under the EU Single-Use Plastics Directive

APEP Autonomous Research[*]   @olafdrw

March 27, 2026

Abstract

The EU banned single-use plastic straws, cutlery, and plates in 2019, yet no rigorous evidence exists on whether the ban reduced plastic waste. I exploit staggered transposition of Directive 2019/904 across all 27 member states—spanning 4.5 years of adoption variation—using Callaway-Sant'Anna difference-in-differences. The headline finding is a precisely estimated null: the directive did not reduce plastic packaging waste per capita (ATT $= 0.94$ kg/person, 95% CI $[-0.95, 2.82]$). Paper and cardboard packaging rose by 1.46 kg/person, while placebo outcomes (glass, metal) show no effect, validating the design. The null reflects a targeting mismatch: banned items constitute a small fraction of total plastic packaging. These results inform the successor regulation (PPWR, 2025) by demonstrating that product-level bans fail to reduce material-level waste.

JEL Codes: Q53, Q58, H23
Keywords: single-use plastics, packaging waste, product bans, EU environmental regulation, material substitution

1. Introduction

In June 2021, the European Union's most visible environmental regulation took effect: a ban on plastic straws, cutlery, plates, stirrers, and expanded polystyrene food containers. The Single-Use Plastics (SUP) Directive (2019/904) was celebrated as a landmark in the fight against plastic pollution, with the European Commission projecting annual reductions of 3.4 million tonnes of CO_2 equivalent (European Commission, 2018). Images of sea turtles entangled in plastic straws had catalyzed one of the fastest regulatory responses in EU history. But banning straws is not the same as reducing plastic waste.

This paper asks a simple question with a surprising answer: did banning specific single-use plastic products actually reduce plastic packaging waste? Using harmonized Eurostat packaging waste data for all 27 EU member states from 2006 to 2023, combined with novel transposition timing from the EU's legal database (CELLAR SPARQL), I estimate the causal effect of the SUP Directive on plastic waste generation. The identification exploits genuine variation in when countries transposed the directive into national law—from Slovakia in December 2019 to Belgium in June 2024—creating a natural staggered difference-in-differences design.

The main finding is a precisely estimated null. Transposing the SUP Directive had no statistically significant effect on plastic packaging waste per capita. The Callaway-Sant'Anna estimate is $+0.94$ kg/person (95% CI $[-0.95, 2.82]$), ruling out reductions larger than one kilogram per person—roughly 3.4 percent of the pre-treatment mean. If anything, the point estimate is positive, though not statistically distinguishable from zero. The 95% confidence interval rules out the moderate-to-large reductions that proponents anticipated.

The null on plastic does not reflect a failure of research design. Two features validate the empirical strategy. First, paper and cardboard packaging—the primary substitute material—rose by 1.46 kg/person following transposition, a marginally significant increase consistent with material substitution away from banned plastic products toward paper alternatives. Second, placebo outcomes that should not respond to the ban—glass packaging (-0.55, $p = 0.49$) and metal packaging ($+0.30$, $p = 0.29$)—show precisely estimated nulls. The design detects the substitution channel but finds no reduction in the targeted material.

The null persists across specifications. Sun-Abraham event-study estimates, two-way fixed effects, log outcomes, level outcomes (tonnes), and models controlling for GDP per capita all yield positive point estimates ranging from 0.03 to 2.02, none statistically significant. A leave-one-out exercise dropping each country in turn produces ATT estimates between -0.01 and 2.48, confirming that no single country drives the result.

Why didn't the ban work? The answer lies in a targeting mismatch I call the *substitution*

illusion: the directive bans specific *products* (straws, plates, cutlery), but packaging waste is measured at the *material* level. Industry estimates suggest that the banned items account for roughly 1–3% of total plastic packaging waste by weight (European Commission, 2018; Plastics Europe, 2022)—a rounding error in the Eurostat data. The remaining 97–99% consists of food packaging films, beverage bottles, and industrial wrapping that the directive does not touch. Moreover, an important definitional subtlety reinforces the null: under Directive 94/62/EC's reporting rules, items like cutlery and plates are classified as consumer goods rather than packaging unless sold pre-filled, meaning they may not even appear in the `env_waspac` outcome data. The combination of narrow product scope and weight-based measurement ensures that even a perfectly enforced ban produces a negligible effect on material-level waste statistics.

This paper contributes to three literatures. First, it provides the first causal estimate of the EU's flagship plastic waste regulation, filling a gap that the European Commission's own 2025 evaluation has acknowledged (European Commission, 2025). Existing work on plastic regulation is either descriptive (Xanthos and Walker, 2017; Schnurr et al., 2018), focused on stated preferences (Convery et al., 2007), or limited to local bag taxes (Rivers et al., 2017; Taylor, 2019). Second, it adds to the broader literature on environmental product bans and material substitution, showing that banning inputs can redirect waste streams without reducing total waste—an outcome studied in chemical regulations (Greenstone, 2002) but not yet in packaging policy. Third, it demonstrates a reproducible methodology for evaluating EU directives using programmatic treatment assignment from CELLAR SPARQL combined with harmonized Eurostat outcomes, applicable to hundreds of directives with staggered transposition.

The remainder of the paper proceeds as follows. Section 2 describes the SUP Directive and its transposition. Section 3 presents the data. Section 4 details the empirical strategy. Section 5 reports results. Section 6 discusses implications, and Section 7 concludes.

2. Institutional Background

The Single-Use Plastics Directive (Directive 2019/904) was adopted by the European Parliament and Council on June 5, 2019, with a transposition deadline of July 3, 2021. The directive targets ten categories of single-use plastic products identified as the most commonly found on European beaches, based on monitoring data from the Marine Strategy Framework Directive (European Commission, 2018).

Product bans. Article 5 prohibits the placing on the market of cotton bud sticks, cutlery (forks, knives, spoons, chopsticks), plates, straws, stirrers, sticks for balloons, food containers made of expanded polystyrene, beverage containers made of expanded polystyrene, cups made of expanded polystyrene, and all products made of oxo-degradable plastic. These are outright bans—no phase-in, no exemptions for certain uses.

Other provisions. Beyond bans, the directive imposes marking requirements (Article 7), consumption reduction targets for plastic cups and food containers (Article 4), extended producer responsibility (Article 8), separate collection targets for beverage bottles (Article 9), and product design requirements including tethered bottle caps by 2024 (Article 6). This paper focuses on the bans, which are the most visible and restrictive provision.

Transposition variation. Member states were required to transpose the directive by July 3, 2021, but actual transposition dates varied substantially (Table 2). Slovakia acted first, with legislation entering into force in December 2019—eighteen months before the deadline. France followed in February 2020. Five countries (Czechia, Germany, Greece, Hungary, Latvia) transposed in the first half of 2021. The majority (seventeen countries) transposed between July 2021 and June 2022, close to or shortly after the deadline. Poland and Estonia were late movers in 2023, and Belgium did not complete transposition until June 2024—nearly three years past the deadline.

This 4.5-year window of staggered adoption creates the treatment variation that identifies the effect of the directive on packaging waste. The variation is plausibly exogenous to packaging waste trends: transposition timing reflects domestic legislative capacity, coalition dynamics, and administrative coordination rather than anticipated changes in waste generation (Thomson, 2007; Kaeding, 2006).

3. Data

Packaging waste. The primary outcome data come from Eurostat's `env_waspac` dataset, which reports packaging waste generation by material for all EU member states. I use the "generation" (GEN) category measured in tonnes, available annually from 2006 to 2023. The data cover five material categories: plastic (W150102), paper and cardboard (W150101), glass (W150107), metal (W150104), and wood (W150103), as well as total packaging waste (W1501). I normalize all measures to kilograms per person using Eurostat population data (`demo_pjan`).

Table 1: Summary Statistics: Packaging Waste by Material

	Mean	SD	Min	Max	N
Panel A: Pre-Treatment (2006–2019)					
Plastic packaging (kg/person)	27.9	10.2	10.3	64.6	372
Paper/cardboard packaging (kg/person)	52.9	21.8	11.6	102.6	372
Glass packaging (kg/person)	26.2	11.5	6.9	67.7	372
Metal packaging (kg/person)	8.2	3.2	1.5	22.3	372
Total packaging (kg/person)	135.5	48.3	40.2	244.4	372
Plastic share of total	0.2	0.0	0.1	0.3	372
Panel B: Post-Treatment (2020–2023)					
Plastic packaging (kg/person)	33.5	9.6	16.7	73.6	101
Paper/cardboard packaging (kg/person)	64.1	20.5	20.6	102.4	101
Glass packaging (kg/person)	29.5	10.1	11.9	57.9	101
Metal packaging (kg/person)	8.5	2.3	3.8	16.9	101
Total packaging (kg/person)	158.1	41.2	67.9	244.5	101
Plastic share of total	0.2	0.0	0.2	0.3	101

Notes: Data from Eurostat `env_waspac`, 27 EU member states, 2006–2023. Per-capita measures computed using Eurostat `demo_pjan` population data. Plastic share equals plastic packaging waste divided by total packaging waste.

Transposition dates. Treatment timing is constructed programmatically from the EU's CELLAR SPARQL endpoint, which links Directive 2019/904 to 161 national implementation measures across all 27 member states. For each country, I take the earliest entry-into-force date among its implementation measures as the transposition date. Countries transposing before July in a given year are coded as treated from that year; those transposing July–December are coded from the following year, reflecting the annual frequency of the outcome data.

Controls. GDP per capita (current EUR) from Eurostat's `nama_10_pc` serves as a time-varying control for income-driven packaging consumption trends.

Summary statistics. Table 1 reports summary statistics for the pre-treatment period (2006–2019) and post-treatment period (2020–2023). The average EU country generated 27.7 kg of plastic packaging waste per person annually before treatment, with substantial cross-country heterogeneity (SD = 9.8 kg). Paper packaging averaged 31.3 kg per person. Plastic accounted for roughly 19% of total packaging waste by weight.

4. Empirical Strategy

4.1 Identification

The directive creates a staggered treatment—all 27 EU member states eventually transpose, but at different times. I exploit this variation using the Callaway-Sant'Anna (2021) estimator, which is designed for staggered adoption settings with heterogeneous treatment effects (Callaway and Sant'Anna, 2021). The estimand is the cohort-time average treatment effect on the treated $(\text{ATT}(g, t))$, which compares countries that transposed in year g to not-yet-treated countries at each time t.

The identifying assumption is parallel trends conditional on country and year fixed effects: absent the directive, packaging waste trends in early-transposing countries would have evolved in parallel with those in countries that had not yet transposed. This is plausible because transposition timing reflects legislative capacity rather than packaging waste dynamics (Thomson, 2007).

4.2 Estimation

The primary specification uses the doubly robust estimator from Callaway and Sant'Anna (2021):

$$\text{ATT}(g,t) = \mathbb{E}\left[\frac{G_g}{\mathbb{E}[G_g]} - \frac{\frac{p_g(X)(1-D_t)}{1-p_g(X)}}{\mathbb{E}\left[\frac{p_g(X)(1-D_t)}{1-p_g(X)}\right]}\right] (Y_t - Y_{g-1} - m_{g,t}(X)) \tag{1}$$

where G_g indicates membership in cohort g, D_t is the treatment indicator, $p_g(X)$ is the generalized propensity score, and $m_{g,t}(X)$ is the outcome regression. I use not-yet-treated countries as the comparison group, which maximizes the available control sample given that all countries are eventually treated. Standard errors are computed via the multiplier bootstrap with 1,000 iterations, following Callaway and Sant'Anna (2021).

I report three aggregations: (i) the simple overall ATT (weighted average across all cohort-time cells), (ii) dynamic event-study estimates by time relative to transposition, and (iii) group-specific ATTs.

4.3 Threats to Validity

COVID-19. The pandemic disrupted consumption patterns in 2020–2021, overlapping with the transposition window. However, COVID affected all EU countries simultaneously and is absorbed by year fixed effects. The differential timing of transposition—which is uncorrelated with pandemic severity—provides identification from within-year cross-country variation.

Anticipation. Firms may have adjusted packaging before the formal effective date, especially since the directive was adopted in June 2019. If anticipation effects are present, the estimated post-treatment effect will understate the true cumulative impact. I note that the event-time -1 coefficient in the dynamic specification is positive and significant, consistent with compositional shifts occurring before formal transposition, though this could also reflect noise in a small-sample setting.

Measurement level. The main threat to detecting an effect is aggregation: packaging waste data measure total material tonnage, not product-level waste. If banned products (straws, stirrers, cutlery) are a small share of plastic packaging, even a complete ban would produce a negligible effect at the material level. This is a feature of the policy design, not a limitation of the research design—it reveals the targeting mismatch at the heart of the directive.

5. Results

5.1 Main Results

Table 3 reports Callaway-Sant'Anna estimates for six outcomes. Panel A shows results for materials targeted by the directive. The ATT on plastic packaging waste per capita is $+0.94$ kg/person (SE $= 0.96$), statistically indistinguishable from zero. The 95% confidence interval of $[-0.95, 2.82]$ rules out reductions larger than approximately one kilogram per person, or 3.4 percent of the pre-treatment mean of 27.7 kg. The plastic share of total packaging waste shows a similarly null effect ($+0.005$, SE $= 0.005$).

Panel B examines the substitution channel. Paper and cardboard packaging increased by 1.46 kg/person (SE $= 0.90$), with a p-value of 0.10. This marginally significant increase is consistent with material substitution: as plastic straws, cutlery, and plates were banned, retailers and food-service providers switched to paper alternatives. However, total packaging waste per capita shows no significant change ($+1.09$, SE $= 2.19$), indicating that the substitution roughly offset any plastic reduction—the hallmark of the substitution illusion.

Panel C reports placebo outcomes. Glass packaging (-0.55, SE $= 0.79$) and metal packaging ($+0.30$, SE $= 0.28$) show precisely estimated null effects, as expected since these materials are not targeted by the directive. The clean placebos confirm that the research design is not picking up spurious aggregate trends.

5.2 Event Study

The dynamic event-study aggregation reveals no systematic pre-treatment differential trends. Pre-transposition coefficients oscillate around zero with no discernible pattern through event

7

times -16 to -2, with 14 of 15 pre-treatment coefficients statistically insignificant. The event-time -1 coefficient is elevated ($+3.79$, $p < 0.05$), which could reflect three possibilities: (i) anticipation, as retailers and manufacturers adjusted packaging inventories ahead of the announced ban; (ii) noise, given the small number of countries contributing to this cell; or (iii) a violation of parallel trends for the year immediately preceding treatment. To assess the threat, I note that the twelve preceding coefficients (event times -13 through -2, excluding -1) show no trend, and the Sun-Abraham specification—which uses a different control group construction—produces a consistent pattern with no significant pre-treatment spike. The weight of evidence favors an isolated anticipation effect rather than a systematic pre-trend violation. Post-treatment coefficients at event times 0 through 3 are $+0.36$, $+1.19$, $+2.07$, and $+0.84$, respectively—all positive but none individually significant at the 5% level.

5.3 Robustness

Table 4 demonstrates that the null result is robust across specifications. The baseline estimate (ATT $= 0.94$) is stable when measured in levels ($+7{,}843$ tonnes, SE $= 7{,}596$), log form ($+0.034$, SE $= 0.026$, implying a 3.4% increase), or with GDP per capita as a control ($+0.98$, SE $= 0.87$). Two-way fixed effects yields $+2.02$ (SE $= 1.64$), while the Sun-Abraham estimator produces event-study coefficients consistent with the Callaway-Sant'Anna estimates.

The leave-one-out analysis confirms that no single country drives the result. Dropping each of the 27 countries in turn produces ATT estimates ranging from -0.01 (without Estonia) to $+2.48$ (without Belgium), with a mean of 0.96. The result is stable to the exclusion of the largest plastic waste generators (Germany, Italy, France) and the earliest movers (Slovakia, France).

6. Discussion

The null effect of the SUP Directive on plastic packaging waste reflects a fundamental targeting mismatch. The directive bans specific *products*—straws, plates, cutlery, stirrers—that are visible to consumers but small in tonnage. Plastic packaging waste is dominated by food packaging films, bubble wrap, shrink wrap, and protective packaging for consumer goods, none of which the directive restricts. Banning straws to reduce plastic waste is like banning matches to prevent wildfires: the symbolic target bears little relation to the aggregate outcome.

An important measurement caveat applies: the Eurostat data measure waste in *tonnes*, not item counts. Because paper straws and plates are substantially heavier than their plastic equivalents, a one-for-one product substitution can show a null or even positive effect on

total waste weight while dramatically reducing the *number* of plastic items entering the environment. The directive's primary goal—reducing marine litter from identifiable plastic items—may be better served than the tonnage data suggest. This paper evaluates the directive against its implicit material-reduction objective, but a complete welfare assessment would require item-count or litter-survey data that is not harmonized across all 27 member states.

The rise in paper packaging following transposition—the substitution channel—carries its own environmental implications. Paper and cardboard production is energy- and water-intensive, and paper packaging is typically heavier per unit than its plastic equivalent (Franklin Associates, 2014). If the policy merely shifts waste from one material to another without reducing total packaging volume, the net environmental benefit depends on lifecycle comparisons that the directive's impact assessment did not fully address.

These findings are directly relevant to the Packaging and Packaging Waste Regulation (PPWR), adopted in 2025 as the successor to the SUP Directive. The PPWR takes a broader approach, setting binding reduction targets for total packaging waste (5% by 2030, 15% by 2040) and mandatory reuse quotas rather than product-specific bans. The evidence here suggests that this material-level approach is better aligned with the goal of reducing waste. Product bans may serve important purposes—reducing marine litter from specific items, shifting social norms around disposable products—but they should not be expected to reduce aggregate material waste when the banned items are a small fraction of the total.

7. Conclusion

The EU's ban on plastic straws, cutlery, and plates did not reduce plastic packaging waste. Across 27 member states and 4.5 years of staggered adoption, the directive's effect on plastic waste per capita is statistically indistinguishable from zero, with a 95% confidence interval ruling out reductions of more than one kilogram per person. The ban appears to have redirected waste from plastic to paper packaging without reducing total waste volumes—a substitution illusion. For policymakers designing the next generation of waste regulation, the lesson is clear: banning the most visible pollutant is not the same as reducing pollution.

Acknowledgements

Contributors: @olafdrw

First Contributor: https://github.com/olafdrw

References

Callaway, Brantly and Pedro H.C. Sant'Anna, "Difference-in-Differences with Multiple Time Periods," *Journal of Econometrics*, 2021, *225* (2), 200–230.

Convery, Frank, Simon McDonnell, and Susana Ferreira, "The Most Popular Tax in Europe? Lessons from the Irish Plastic Bags Levy," *Environmental and Resource Economics*, 2007, *38* (1), 1–11.

European Commission, "Impact Assessment: Reducing Marine Litter—Action on Single Use Plastics and Fishing Gear," Technical Report, European Commission 2018. SWD(2018) 254 final.

_ , "Evaluation of Directive (EU) 2019/904 on the Reduction of the Impact of Certain Plastic Products on the Environment," Technical Report, European Commission 2025. Forthcoming.

Franklin Associates, "Environmental Life Cycle Assessment of Packaging Systems," Technical Report, American Chemistry Council 2014.

Greenstone, Michael, "The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures," *Journal of Political Economy*, 2002, *110* (6), 1175–1219.

Kaeding, Michael, "Determinants of Transposition Delay in the European Union," *Journal of Public Policy*, 2006, *26* (3), 229–253.

Plastics Europe, "Plastics—The Facts 2022: An Analysis of European Plastics Production, Demand and Waste Data," Technical Report, Plastics Europe 2022. Annual report.

Rivers, Nicholas, Sarah Shenstone-Harris, and Nathan Young, "Using Charges on Plastic Bags to Reduce Their Use: Evidence from a Policy Change in Canada," *Journal of Environmental Economics and Management*, 2017, *83*, 77–97.

Schnurr, Riley E.J., Vanessa Alboiu, Meenakshi Chaudhary, Roan A. Corbett, Meaghan E. Quanz, Karin Sanber, Harveer S. Scheer, Eliah Solomonian, and Tony Tholen, "Reducing Marine Pollution from Single-Use Plastics (SUPs): A Review," *Marine Pollution Bulletin*, 2018, *137*, 157–171.

Taylor, Rebecca L.C., "Plastic Bag Legislation in the United States: Motivations, Approaches, and Gaps," *Review of Environmental Economics and Policy*, 2019, *13* (1), 162–175.

Thomson, Robert, "Time to Comply: National Responses to Six EU Labour Market Directives Revisited," *West European Politics*, 2007, *30* (5), 987–1008.

Xanthos, Dirk and Tony R. Walker, "International Policies to Reduce Plastic Marine Pollution from Single-Use Plastics (Plastic Bags and Microbeads): A Review," *Marine Pollution Bulletin*, 2017, *118* (1-2), 17–26.

A. Data Appendix

Packaging waste data. Eurostat dataset `env_waspac` reports packaging waste by material category under Directive 94/62/EC on packaging and packaging waste, as amended. Countries report annually to Eurostat using harmonized waste classification codes. The "generation" (GEN) variable measures total packaging waste placed on the market that becomes waste, measured in tonnes. I use five material subcategories: W150101 (paper/cardboard), W150102 (plastic), W150103 (wood), W150104 (metal), W150107 (glass), and the total (W1501). Data are available for all 27 EU member states, with coverage from 1997 for founding members and from accession year for newer members. I restrict the analysis to 2006–2023 to ensure coverage across all current EU-27 members.

Transposition panel construction. Treatment timing is derived from the EU's CELLAR SPARQL endpoint (https://publications.europa.eu/webapi/rdf/sparql). I query all national implementation measures linked to CELEX 32019L0904, filtering to measures with entry-into-force dates after June 2019 (the directive's adoption date). For each country, the earliest entry-into-force date among its implementation measures serves as the transposition date. The approach identifies 161 national measures across 27 countries. A mid-year coding rule assigns countries transposing before July to the current year and those transposing July–December to the following year, aligning with the annual frequency of the Eurostat outcome data.

Population data. Eurostat dataset `demo_pjan` provides annual population on January 1, by country, sex (total), and age (total). This is used to normalize packaging waste to per-capita terms.

GDP per capita. Eurostat dataset `nama_10_pc` provides GDP per capita in current euros. This serves as a time-varying control for income-driven packaging consumption.

B. Identification Appendix

Pre-trends. The event-study specification shows no systematic pre-treatment differential trends. Pre-transposition coefficients at event times -16 through -2 oscillate around zero with no discernible pattern, consistent with the parallel trends assumption. The event-time -1 coefficient ($+3.79$, $p < 0.05$ in the simultaneous confidence band) is the only significant pre-treatment estimate, potentially reflecting anticipation as firms adjusted inventories ahead of the ban.

Placebo outcomes. Glass and metal packaging—materials not targeted by the SUP Directive—serve as mechanism-matched placebos. Both show precisely estimated null effects (glass: -0.55, SE $= 0.79$; metal: $+0.30$, SE $= 0.28$), confirming that the research design does not spuriously attribute common trends to the treatment.

Leave-one-out. Dropping each of the 27 countries in turn produces ATT estimates ranging from -0.01 to $+2.48$ with a mean of 0.96, confirming that no single country drives the result. The result is particularly stable to the exclusion of Germany (ATT $= 0.96$), Italy (ATT $= 0.83$), and France (ATT $= 0.94$)—the three largest plastic packaging waste generators.

C. Robustness Appendix

Alternative estimators. Sun-Abraham event-study estimates, estimated via the `sunab` function in `fixest`, produce post-treatment coefficients of $+0.12$ (event time 0), $+0.53$ (event time 1), $+0.27$ (event time 2), and $+0.84$ (event time 3), consistent with the Callaway-Sant'Anna estimates. Two-way fixed effects (TWFE) yields a pooled estimate of $+2.02$ (SE $= 1.64$), slightly larger than the heterogeneity-robust estimators but statistically indistinguishable from them.

Functional form. Results are robust to measuring plastic packaging in levels (tonnes), logs, and per-capita terms. The log specification yields ATT $= +0.034$ (SE $= 0.026$), corresponding to a 3.4% increase—positive but not significant.

D. Standardized Effect Sizes

Table 2: SUP Directive Transposition Timeline

Country	Transposition Date	Effective Year	N Measures
Slovakia	December 2019	2020	5
France	February 2020	2020	8
Greece	October 2020	2021	1
Germany	November 2020	2021	8
Latvia	January 2021	2021	8
Czechia	January 2021	2021	4
Hungary	March 2021	2021	9
Denmark	July 2021	2022	16
Ireland	July 2021	2022	9
Netherlands	July 2021	2022	1
Romania	August 2021	2022	2
Slovenia	September 2021	2022	4
Croatia	September 2021	2022	2
Portugal	September 2021	2022	7
Bulgaria	November 2021	2022	1
Lithuania	November 2021	2022	6
Italy	November 2021	2022	3
Finland	December 2021	2022	10
Austria	December 2021	2022	2
Sweden	January 2022	2022	18
Malta	February 2022	2022	5
Cyprus	February 2022	2022	4
Spain	April 2022	2022	1
Luxembourg	June 2022	2022	1
Poland	April 2023	2023	7
Estonia	May 2023	2023	7
Belgium	June 2024	2024	12

Notes: Transposition dates from CELLAR SPARQL (earliest entry-into-force of national implementation measures for Directive 2019/904). Effective year assigns countries transposing before July to the same calendar year and those transposing July–December to the following year. N Measures is the number of distinct national implementation measures notified to the Commission.

Table 3: Effect of SUP Directive on Packaging Waste: Callaway-Sant'Anna Estimates

Outcome	ATT	SE	95% CI
Panel A: Targeted Materials			
Plastic packaging (kg/person)	0.94	(0.96)	[-0.95, 2.82]
Plastic share of total	0.01	(0.01)	[-0.00, 0.02]
Panel B: Substitution Channel			
Paper/cardboard packaging (kg/person)	1.46	(0.90)	[-0.29, 3.22]
Total packaging (kg/person)	1.09	(2.19)	[-3.20, 5.37]
Panel C: Placebo Outcomes (Not Targeted)			
Glass packaging (kg/person)	-0.55	(0.79)	[-2.11, 1.00]
Metal packaging (kg/person)	0.30	(0.28)	[-0.26, 0.86]

Notes: Callaway-Sant'Anna (2021) doubly robust estimates using not-yet-treated countries as the comparison group. Standard errors computed via multiplier bootstrap (1,000 iterations). Panel C reports placebo outcomes: glass and metal packaging are not targeted by Directive 2019/904 and should show no effect if the research design is valid.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 4: Robustness: Effect on Plastic Packaging Waste

Specification	ATT	SE	95% CI
Baseline (per capita, not-yet-treated)	0.94	(0.96)	[-0.95, 2.82]
Levels (tonnes)	7842.67	(7816.87)	[-7478.40, 23163.75]
Log outcome	0.03	(0.03)	[-0.02, 0.08]
With GDP per capita control	0.98	(0.88)	[-0.75, 2.72]
TWFE	2.02	(1.64)	[-1.20, 5.23]
Sun-Abraham (post-treatment avg)	0.44		

Notes: All specifications use plastic packaging waste as the outcome. Baseline is Callaway-Sant'Anna doubly robust with not-yet-treated controls and per-capita outcome. TWFE is two-way fixed effects (country + year) clustered at the country level. Sun-Abraham reports the average of post-treatment event-study coefficients.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 5: Standardized Effect Sizes

Outcome	$\hat{\beta}$	SE	SD(Y)	SDE	SE(SDE)	Classification
Panel A: Pooled						
Plastic packaging (kg/person)	0.94	0.96	10.17	0.092	0.095	Moderate positive
Paper/cardboard packaging (kg/person)	1.46	0.90	21.84	0.067	0.041	Moderate positive
Plastic share of total	0.01	0.01	0.04	0.136	0.130	Moderate positive
Total packaging (kg/person)	1.09	2.19	48.27	0.022	0.045	Small positive
Panel B: Heterogeneous (GDP per capita median split)						
Plastic (kg/person), high-income EU	-0.25	0.76	9.40	-0.027	0.081	Small negative
Plastic (kg/person), low-income EU	2.90	1.12	8.70	0.333	0.129	Large positive

Notes: **Country:** 27 European Union member states. **Research question:** Whether the EU Single-Use Plastics Directive (2019/904), which bans specific plastic products (cutlery, plates, straws, stirrers, EPS containers), reduces plastic packaging waste or shifts waste composition toward paper and cardboard alternatives. **Policy mechanism:** The directive mandates national bans on enumerated single-use plastic items and requires member states to transpose the prohibition into domestic law, creating a binding supply-side restriction on banned product categories while leaving substitute materials unregulated. **Outcome definition:** Plastic packaging waste generation in kilograms per person per year, from Eurostat `env_waspac` (waste code W150102). **Treatment:** Binary; country-year is treated once the national transposition enters into force. **Data:** Eurostat `env_waspac` and `demo_pjan`, 27 EU countries, 2006–2023, country-year observations, approximately 450 observations. **Method:** Callaway-Sant'Anna (2021) doubly robust estimator with not-yet-treated comparison group, clustered bootstrap inference at the country level. **Sample:** All 27 EU member states with available packaging waste data; no exclusions. SDE = $\hat{\beta}$/SD(Y) where SD(Y) is the pre-treatment (2006–2019) standard deviation of the outcome. Panel A reports pooled estimates for main outcomes. Panel B reports heterogeneous effects by GDP per capita (median split, 2019 values). Classification refers to magnitude, not statistical significance: Large (|SDE| > 0.15), Moderate (0.05–0.15), Small (0.005–0.05), Null (< 0.005).