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Impact of E-Waste Regulations on Firms' R&D and Marketing Expenditures: Insights for a Circular Economy

Abstract

Shorter product lifecycles and rising consumer demand drive the rapid expansion of electronic garbage, or e-waste, presenting environmental and public health issues. Governments worldwide have implemented e-waste recycling regulations to control the collection, recycling, and disposal of electronic trash. These regulations are intended to reduce harmful pollution, preserve resources, and promote a circular economy. However, firms associated with the electronic products industry have to limit the resource allocation on long-term strategies due to compliance with these e-waste regulations. We investigate the impact of e-waste regulations on the R&D and marketing expenditures of firms producing or selling electronic products. Using Standard Industrial Classification codes to identify industries linked to electronic equipment, this study examines the effects of state-level e-waste legislation in the U.S. on business practices, with a particular emphasis on R&D and marketing expenditures. We examine changes in businesses impacted by e-waste regulations compared to those in states with no regulations, using a difference-in-differences methodology using a 30-year dataset (1993-2023). The results highlight trade-offs between satisfying regulatory requirements and promoting innovation, showing that e-waste regulations result in lower R&D and marketing expenditures. These findings are validated by robustness testing that uses bootstrapping and extended DID. Our research has several theoretical and practical recommendations.

Keywords: E-waste policies, R&D expenditures, marketing expenditures, circular economy

1. Introduction

The ever-increasing pace of technological breakthroughs and consumer demand for new products is driving the fast-growing global problem of electronic waste (or e-waste). The production of large amounts of e-waste and inadequate disposal practices lead to environmental degradation and health hazards. According to the UN's Global E-waste Monitor, only 22.3% is adequately processed, fuelling widespread ecological and health hazards (Unitar, 2022). E-waste is expanding at an unprecedented rate due to mass electronic adoption, deliberate obsolescence in product design, and increasingly shortened usage cycles. The escalating volume of e-waste amplifies environmental pollution, resource depletion, and unequal waste treatment, with many developing countries becoming dumping grounds for e-waste (Sthiannopkao and Wong, 2013). Given that businesses are the principal generators of

e-waste, stronger and more inclusive regulations are needed to ensure accountable and efficient waste processing (Khetriwal et al., 2009).

As the consequences of electronic waste become increasingly clear, policymakers are intensifying efforts to develop regulatory frameworks. The purpose of these policies is to manage toxic materials responsibly and optimize the recovery of valuable resources through organized e-waste collection and recycling systems. Several countries now require manufacturers to be responsible for collecting, recycling, or properly disposing of their products after consumers are done using them (Atasu and Subramanian, 2012; Liu et al., 2023). Efforts to ensure proper e-waste disposal increasingly emphasize public education, formal recycling systems, and partnerships with licensed recyclers. By addressing the risks of e-waste to environmental and human health, these initiatives also drive resource conservation and promote a more circular and resilient economic model.

The implementation of e-waste legislation affects the manufacturing of electronic products and related businesses, requiring them to reallocate resources to maintain compliance. In order to comply with these new laws, businesses have been forced to cut back on spending on specific initiatives and place a greater focus on sustainability. We propose that firms reduce their R&D and marketing expenditures to comply with e-waste recycling policies. The earlier research thoroughly examined the effects of e-waste regulations on a number of variables, including public health outcomes (Kiddee et al., 2013), waste management effectiveness (Patil and Ramakrishna, 2020), and environmental sustainability (Herat, 2007). Research has frequently shown how successful laws are at lowering hazardous waste (Ilankoon et al., 2018), encouraging recycling (Wang and Huo, 2023), and developing circular economy principles (Guzzo et al., 2021; Sun et al., 2023). However, there is a clear lack of discussion regarding how these policies affect resource allocation across industries, especially when it comes to trade-offs like lower marketing and R&D expenditures. Hence,

we are the earliest ones to focus on this issue. In this research, we focus on the below research questions:

Research Question 1: How does e-waste policy implementation impact firms' R&D expenditures?

Research Question 2: How does e-waste policy implementation impact firms' marketing expenditures?

With an emphasis on R&D and marketing expenditures in industries related to electronic equipment, as indicated by major Standard Industrial Classification (SIC) codes, this study investigates the effects of state-level e-waste restrictions on the corporate behaviour of U.S. publicly traded firms. Using a difference-in-differences (DID) method using a 30-year dataset (1993–2023), the analysis contrasts trends in businesses impacted by e-waste rules with those in states with no such laws. The chronology and extent of regulations, starting with the 2003 statute in California, offer a foundation for comprehending how resource allocation, innovation, and strategic planning are impacted by regulatory compliance in the manufacturing, retail, recycling, and logistics sectors. With the institutional theory framework and DID analysis, we find that the implementation of e-waste policies leads to a decrease in electronic products associated firms' R&D and marketing expenditures. We also performed an extended DID and bootstrapping method to provide robustness to our analysis. Our results are robust and support the two hypotheses empirically. Our study has several implications.

We contribute to both institutional and signalling theory by showing, in a real-world context, how compliance with e-waste regulations adjusts firms' internal priorities, depends less on outward signalling, and influences their long-term strategic decisions. By integrating insights from institutional and signalling theory, we explain how firms balance the need for

external legitimacy with internal strategic priorities under regulatory pressure. According to institutional theory, firms respond to external pressures to secure legitimacy and maintain their position within the broader institutional environments (Caprar and Neville, 2012; Chen and Filieri, 2024). Signalling theory complements this perspective by showing how firms communicate legitimacy to stakeholders through clear and credible actions that comply with regulatory policies (Connelly et al., 2011; Ding et al., 2024). When compliance is both highly visible and resource-intensive, it becomes a compelling indicator of legitimacy, especially in domains such as environmental governance. This diminishes the need for supplementary marketing or reputation-enhancing efforts because institutional conformity already establishes legitimacy (Zott and Huy, 2007). We integrate these frameworks and provide a deeper insight into how firms adjust their resources to align with external expectations within evolving institutional contexts. The managerial suggestions are using partnerships to split the cost of compliance, investing in sustainable technology to balance innovation and compliance, and integrating circular economy concepts into projects to increase market competitiveness and regulatory compliance.

The rest of the manuscript is organized as follows. We discuss the theoretical framework and formulation of hypotheses in section 2. Section 3 describes data collection, and the research method used to support hypotheses. We present and discuss the results in section 4. Section 5 contains the extended DID model with bootstrapping as a robustness check. We provide study discussion and implications in section 6. Section 7 presents the conclusion, limitations, and future research directions.

2. Theoretical analysis and research hypotheses

State e-waste recycling regulations are implemented based on a combination of economic, health, environmental, and circular economy factors. E-waste is the term used to describe abandoned equipment and devices that are no longer wanted or usable (Amankwah-

Amoah, 2016). It encompasses various items, such as consumer electronics, home appliances and office supplies. E-waste is one of the waste streams with the greatest rate of growth as a result of the volume of discarded electronics increasing along with technological improvements (Shahabuddin et al., 2023). Electronic waste contains several hazardous materials, such as brominated flame retardants, cadmium, lead, and mercury (Joon et al., 2017). These substances can discharge into soil, air, and water, damaging ecosystems if they are not properly recycled (Modgil et al., 2021). Hence, e-waste recycling is necessary for sustaining a clean environment and lessening long-term ecological harm.

From the perspective of public health, exposure to harmful substances found in e-waste can result in serious health problems (Allsopp et al., 2006). State regulations guarantee that e-waste is managed at facilities that are subject to regulations and have the necessary safety precautions, reducing health risks for both employees and the general public. Economically speaking, e-waste has the potential to yield precious elements such as rare earth metals, copper, palladium, and others that are essential for creating new electronic gadgets (Mueller et al., 2015). Recycling these limited resources helps preserve natural resources, lessens dependency on damaging mining methods, and eliminates the need to import raw materials. Additionally, recycling promotes the growth of green-collar jobs and strengthens local economies by creating jobs in the trash management, repair, and refurbishing industries (Leigh et al., 2012).

The transition to a circular economy supports the implementation of e-waste regulations and emphasises the importance of recycling. The circular economy is different from the traditional linear disposal-focused economy and aims to maximise the utility of products by keeping them in use for as long as they can be (Dwivedi et al., 2022). By encouraging firms to design electronics with extended durability, interchangeable parts, and easier maintainability, e-waste recycling laws support the creation of a closed-loop system in which

used goods are recycled back into the manufacturing process. This process helps mitigate environmental harm and encourages more sustainable consumer behaviour (Sharma and Foropon, 2019). Hence, these state government regulatory e-waste policies promote eco-friendly practices and reclaim valuable resources.

The institutional theory looks at how businesses adjust and react to the demands and expectations placed on them by their institutional environment, including laws, social conventions, cultural values, and industry standards (Chen and Filieri, 2024). According to this framework, organisations adapt to state-led policies in an effort to gain legitimacy, stability, and survival, which can greatly influence their strategic decision-making (Geels, 2020). Organisations encounter coercive pressures that are brought about by official policies, rules, and laws that are enforced by governments or other authoritative entities (Markoff-Legrand et al., 2024). They are also subjected to normative pressures resulting from social expectations, professional norms, and industry standards (Liu et al., 2024).

These coercive and normative pressures may modify the strategic decisions of firms regarding long-term growth. The institutional theory suggests that firms have to comply with regulations. E-waste policies enforce strict guidelines on product development, end-of-life management, and recycling. Businesses have to prioritise modifications that adhere to these regulatory requirements in order to comply. As a result, they spend money on compliance-driven initiatives rather than creative, long-term R&D initiatives. Businesses may prioritise short-term compliance over future-focused innovation as a result of the pressure to fulfil regulatory deadlines and avoid penalties. Financial and human resources would be allocated to supply chain adaptation, product redesign for recyclability, and waste recovery program management in order to comply with e-waste regulations. Resources for R&D endeavours, especially those centred on game-changing discoveries, are reduced as a result of this reallocation. Firms are influenced by institutional forces to reorder their resources, making

compliance a more pressing issue than innovation. Firms also comply with regulations in order to avoid the risk of misconduct or penalties, which diminishes the desire to invest in R&D projects (Schantl and Wagenhofer, 2021). Based on these reasons, we proposed the below hypothesis:

Hypothesis 1*. The implementation of e-waste policies leads to a decrease in the R&D expenditures of firms.*

The institutional theory offers a framework of mimetic pressure, where businesses frequently copy the tactics of their industry peers in order to gain credibility and stay competitive in the market (Martínez-Ferrero and García-Sánchez, 2017). Firms, while following e-waste regulations, send a signal to stakeholders regarding legitimacy and environmental consciousness (Song et al., 2024). Firms' marketing and promotional campaigns also act as signals to build trust among stakeholders (Chiu and Chen, 2014). However, by adhering to the e-policy legislation, businesses that already have e-waste programs automatically convey legitimacy to stakeholders. Firms' dedication to environmental standards is demonstrated by this compliance, which meets the minimum requirements set by stakeholders. As a result, any marketing expenditures to further signal or communicate the same compliance can be seen as unnecessary and a waste of money. Firms' actions have already demonstrated their validity; therefore, there is no need for additional money to be spent on double signalling. Additionally, the mimetic pressure influences firms within industries to avoid seeming out of line with industry norms if they choose not to spend more on marketing strategies, since it is seen as redundant. The concept that marketing for double signalling is unnecessary because compliance alone is sufficient to sustain legitimacy within the institutional framework is reinforced by this collective behaviour. As a result of these dynamics, there may be a general trend in the industry for businesses to concentrate their resources on real compliance measures instead of marketing campaigns. Furthermore, it

keeps money from going to marketing campaigns that stakeholders might consider unnecessary or wasteful. Hence, we propose the following hypothesis:

Hypothesis 2. *The implementation of e-waste policies leads to a decrease in firms' marketing expenditures.*

To establish a clear link between our theory, hypotheses, and testing strategy, we need to highlight how institutional forces in the real world guide our methodology. These regulations around e-waste at the state level are shaped by a mix of environmental, health, and circular economy priorities. These policies, through both legal requirements and social expectations, encourage firms to prioritise and adjust their spending. As our hypotheses suggest, complying with these regulations may result in firms dialling down their budgets for R&D and marketing. Since state regulations vary in both timing and approach, a strong empirical approach is needed to capture these differences and understand their impact on firms. To address these variations, we consider a method that tracks state-level e-waste regulations across time and geography to study the effects on firms. It allows us to clearly see how companies change their budgets to meet these institutional demands. This approach grounds our hypotheses in theory and provides a framework for a clear and robust research design in the next section.

3. Data and research design

3.1. Data collection

We collect state-level electronic waste (e-waste) policies and programs in the United States, along with the years in which these programs were put into place. It draws attention to the legal initiatives taken by different state governments to address the problems with electronic waste that affect the environment and public health. Table 1 provides information on the state-level e-waste policies for different U.S. states, along with the year of

implementation. The analysis of these e-waste policies offers insightful information that can directly bolster and validate the hypotheses about how corporate behaviour and resource allocation are affected by regulatory compliance. We can examine how businesses operating in these states reallocate their resources in response to compliance requirements by looking at the chronology and strictness of these e-waste policies. As Table 1 suggests, the policies' breadth and focus vary with respect to adoption years, which helps us to study temporal trends due to the implementation of policies. States have different titles for their regulations, but they all have the same basic goal of solving the problem of handling and recycling electronic trash. Regardless of the program's exact name, all of them stress how to reduce environmental damage and encourage sustainable practices by properly disposing of, recycling, and reusing electronic gadgets. Hence, these policies are suitable for our analysis.

Table 1

State-level e-waste management laws and programs in the United States

State	Law/Program	Adoption year
California	Electronic Waste Recycling Act of 2003	2003
Connecticut	E-Waste Recycling Law	2007
Hawaii	Hawaii Electronic Device Recycling and Recovery Act	2009
Illinois	Electronic Products Recycling and Reuse Act	2008
Maine	E-Waste Recycling Program	2004
Maryland	Maryland Electronics Recycling Program	2005
Michigan	Michigan Electronics Takeback Program	2008
Minnesota	Minnesota Electronics Recycling Act	2007
New York	Electronic Equipment Recycling and Reuse Act	2010
North Carolina	NC Electronics Management Program	2010
Oregon	Oregon E-Cycles Program	2007
Rhode Island	Electronic Waste Prevention, Reuse, and Recycling Act	2008
South Carolina	SC Manufacturer Responsibility and Consumer Convenience Information Technology Equipment Collection and Recovery Act	2010
Vermont	Vermont E-Waste Program	2011
Washington	E-Cycle Washington	2006

The main goal of this study is to investigate the effects of state-level e-waste regulations on companies in particular industries. We want to ascertain how these policies affect R&D and marketing expenditures in the impacted industries by examining their timeline, scope, and strictness. The primary focus of the study is on industries that fall under particular Standard Industrial Classification (SIC) codes and are either directly or indirectly impacted by e-waste laws at the state level. From manufacturing and distribution to disposal and recycling, these sectors are essential to the lifecycle of electronic equipment. Much of the design and production of electronic devices falls under SIC code 36, which includes a broad range of electrical and electronic components. Industries engaged in the production and processing of cutting-edge technological equipment are represented by SIC code 35, which comprises Industrial and Commercial Machinery and Computer Equipment. The retail side of consumer electronics, where appropriate handling of end-of-life gadgets becomes essential, is also highlighted by SIC code 57, which covers Home Furniture, Furnishings, and Equipment Stores. Furthermore, SIC code 49, which encompasses Electric, Gas, and Sanitary Services, highlights recycling and waste management, underscoring the environmental impact of disposing of e-waste. Last but not least, the logistics and transportation services necessary for the collection and delivery of e-waste to recycling facilities are covered by SIC code 42, Motor Freight Transportation and Warehousing. These are the sectors represented by the first two-digit SIC codes we focus on for our analysis.

We gather comprehensive firm-level data for businesses in the designated SIC code sectors throughout the United States using the Compustat database. In 2003, California became the first state to implement an e-waste regulation, serving as the foundation for the research. We examine how companies adjust their R&D and marketing resource allocation over time in reaction to these regulatory changes. The inclusion of a ten-year pre-policy timeframe (1993 onwards) serves as a baseline for corporate operations before regulatory

action. The dataset covers a 30-year period, from 1993 to 2023, which allows us to analyse how firms modified their R&D innovation and marketing intensities in response to compliance requirements because it covers enterprises operating in the targeted sectors associated with electronic equipment for each policy-implementing state. The dataset and the analysis provide insight into the influence of government regulatory policies on shaping firms' allocation of resources and strategic decision-making.

3.2. Analysis

We use the difference-in-differences (DID) method to empirically support our hypotheses. The DID method is a statistical technique to compare the changes in outcomes over time between a group that is exposed to the policy (the treated group) and a group that is not exposed (the control group) in order to assess the causal effects of policies (Wu et al., 2022). When randomisation is not practical for observational investigations, this approach is especially helpful (Gao et al., 2023). The DID method's main concept is to isolate the trend differences between the treatment and control groups in order to quantify the impact of a policy. The approach assumes that the developments in the outcome variables (R&D and marketing expenditures) for both groups would have been parallel in the absence of the policy. The general equation of the DID analysis is given below:

$$Y_{ist} = \alpha + \beta * Policy_{st} + \gamma * T_s + \delta * P_t + \epsilon_{ist} \quad \text{.....(1)}$$

where,

Y_{ist} = Outcome variable for *i*th firm in state *s* at time *t*

α = Constant term

$Policy_{st}$= Policy dummy variable, which is equal to 1 if the policy is implemented in state *s* at time *t*, and 0 otherwise.

β = Coefficient to measure the causal impact of the policy implementation

T_s = State s unique characteristics

P_t = Time fixed effects which capture shocks or trends common to all states

ϵ_{ist} = Error term

The DID estimator determines the average change in the outcome variable before and after the policy's implementation between the treatment and control groups. It can be stated as follows:

$$DID\ Estimator = \left[Y_{treated,post} - Y_{treated,pre}\right] - \left[Y_{control,post} - Y_{control,pre}\right] \ldots.(2)$$

In the above equation, $Y_{treated,pre}$ and $Y_{treated,post}$ are the average outcomes of the treated group before and after the policy adoption. However, $Y_{control,pre}$ and $Y_{control,post}$ are the average outcomes of the control group before and after the policy adoption.

We use the DID approach to analyse e-waste policies by contrasting states that adopted e-waste policies (treatment group) with those that did not (control group) within the same time period. We consider percentage changes in R&D and marketing expenditures with respect to the prior years as our dependent variables to find out the impact of policy adoption in different states following prior literature (Cheng, 2004; Graham and Frankenberger, 2011; Ptok et al., 2018). A binary variable is used to capture whether a policy was in force for a particular state in a given year. The study includes state-fixed effects (T_s) to control for state-specific factors, which adjust for time-invariant characteristics unique to each state. We also include time-fixed effects (P_t) in order to account for national patterns, including macroeconomic shifts, that could have an equal impact on every state. Because states adopted e-waste policies in different years, we follow the staggered treatment design, which is more

relevant to our dataset. This variation in timing helps us isolate the effects of the policy by comparing firms across states and over time (Goodman-Bacon, 2021).

We provide the trends of mean percentage in R&D and marketing expenditures of the targeted industry firms in figures 1 and 2. Figure 1 shows the trends in mean percentage change of R&D expenditure with a maximum of 3.08 % and a minimum of -0.06 %. The mean value of the percentage change in R&D expenditure is 0.41%, with a standard deviation of 0.17%. Figure 2 shows the trends in the mean percentage change of marketing expenditure with a maximum of 1.61 % and a minimum of -0.001 %. The mean value of percentage change in marketing expenditure is 0.34 %, with a standard deviation of 0.32 %.

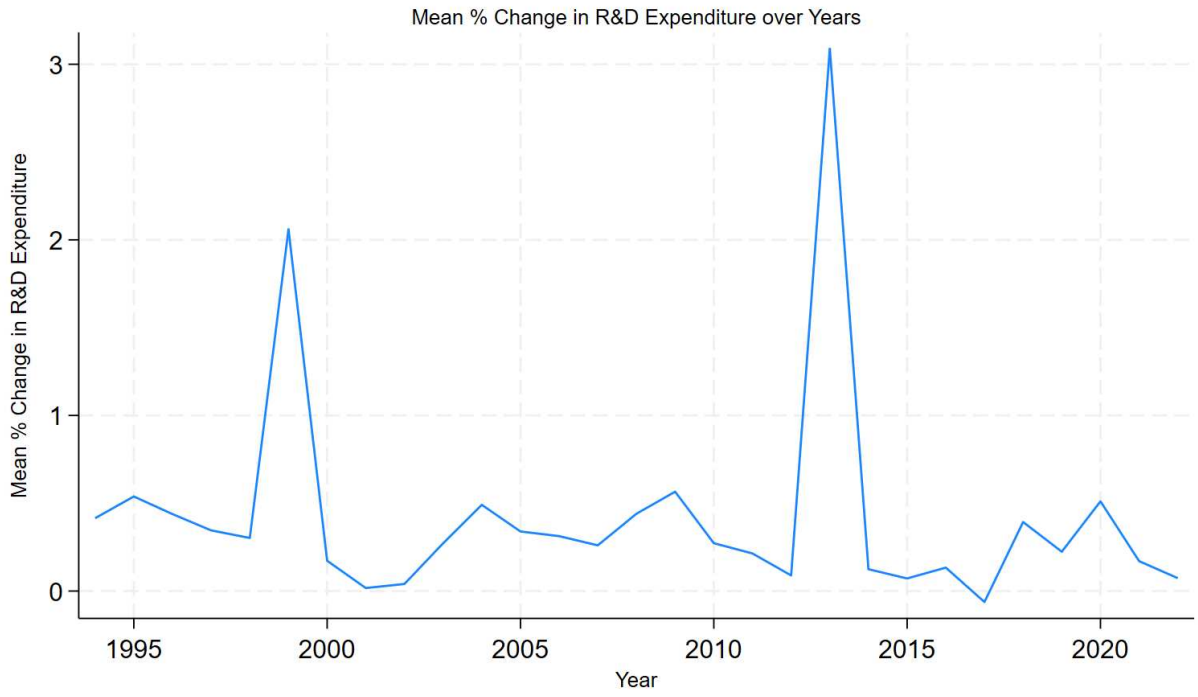

Fig.1. Trends in the mean percentage change of R&D expenditure over time

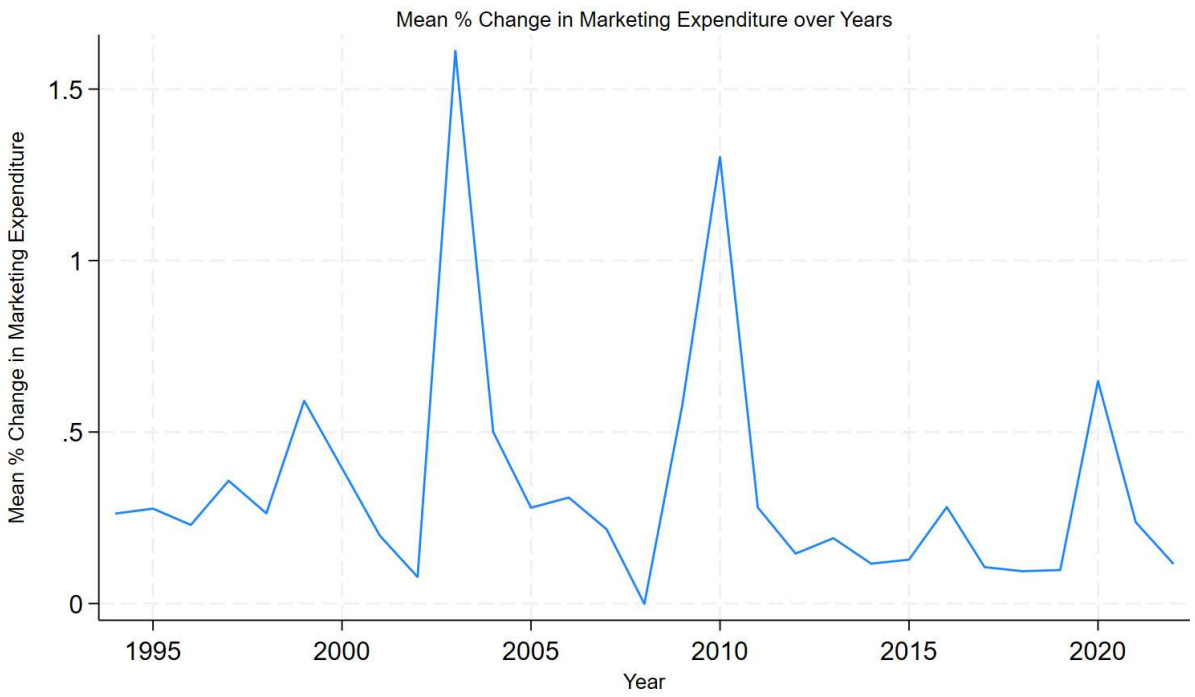

Fig.2. Trends in the mean percentage change of marketing expenditure over time

We use Equation (1) for the estimation. Table 2 provides the information on the variables corresponding to each term in Equation (1). Percentage changes in R&D and marketing expenditures are our dependent variables. We construct our treatment variable by the multiplication of a policy-year dummy (equal to 1 after the policy is implemented) and a state-level dummy (set to 1 if the policy has been enacted in the respective state). This guarantees that the state in which the policy is in effect, as well as the particular years that the policy is in effect, are captured by the treatment variable. To provide a reliable treatment effect assessment, we additionally include state and time-fixed effects in our DID model. The state-fixed effects take into consideration unobserved traits unique to certain states or businesses that don't change over time. They are represented by the targeted firms' unique identities (GVKEY). We use a year variable which reflects the temporal dynamics that may impact all firms and states in a given year. The consideration of this year and the time-fixed effects helps us remove other factors that may lead to biased results.

Table 2

Mapping data variables to theoretical DID model components

Equation variable	Data variable	Description
Y_{ist}	Percentage change in R&D and marketing expenditures	Dependent Variables for firm *i* in state *s* at time *t*.
$Policy_{st}$	Treatment variable	Binary treatment variable indicating whether state *s* had an e-waste policy implemented in year *t*.
T_s	Targeted firms GVKEY	Group identifier for targeted firm-specific fixed effects
P_t	Year	Time identifier for time fixed effects
ϵ_{ist}	Implicit	Residual for unobserved factors

4. Overall results

4.1. Impact of policy adoption on R&D expenditure

We first draw the comparison graph of treatment and control groups to check the impact of policy implementation on the R&D expenditures of the targeted firms. The control group, which consists of businesses in states without e-waste policies, is represented by the blue line. The treated group, which consists of businesses in states with e-waste policies, is represented by the red line. Over time, R&D spending varies for both groups, but the patterns are different, especially following the implementation of the policy. Both groups' pre-treatment trends seem to be quite parallel, which supports the assumption that parallel trends are necessary for the DID analysis to be valid. However, the average changes in R&D expenditures are marginally greater in the control group than in the treated group during the post-treatment period. The treated group deviated somewhat lower from the control group when the policy was implemented (from 2003 onwards). This implies that, in comparison to

firms in the control group, firms in the treated states saw a reduced average percentage change in R&D expenditure. The observed discrepancy after 2003 would suggest that firms in the treated group possibly shifted funds from R&D to compliance expenses as a result of the implementation of the e-waste legislation. According to Figure 3, R&D spending for treatment firms is reduced in comparison to control firms as a result of the implementation of e-waste legislation. Hence, the sample analysis supports our H1 and the use of DID analysis helps to generalize results for a larger population.

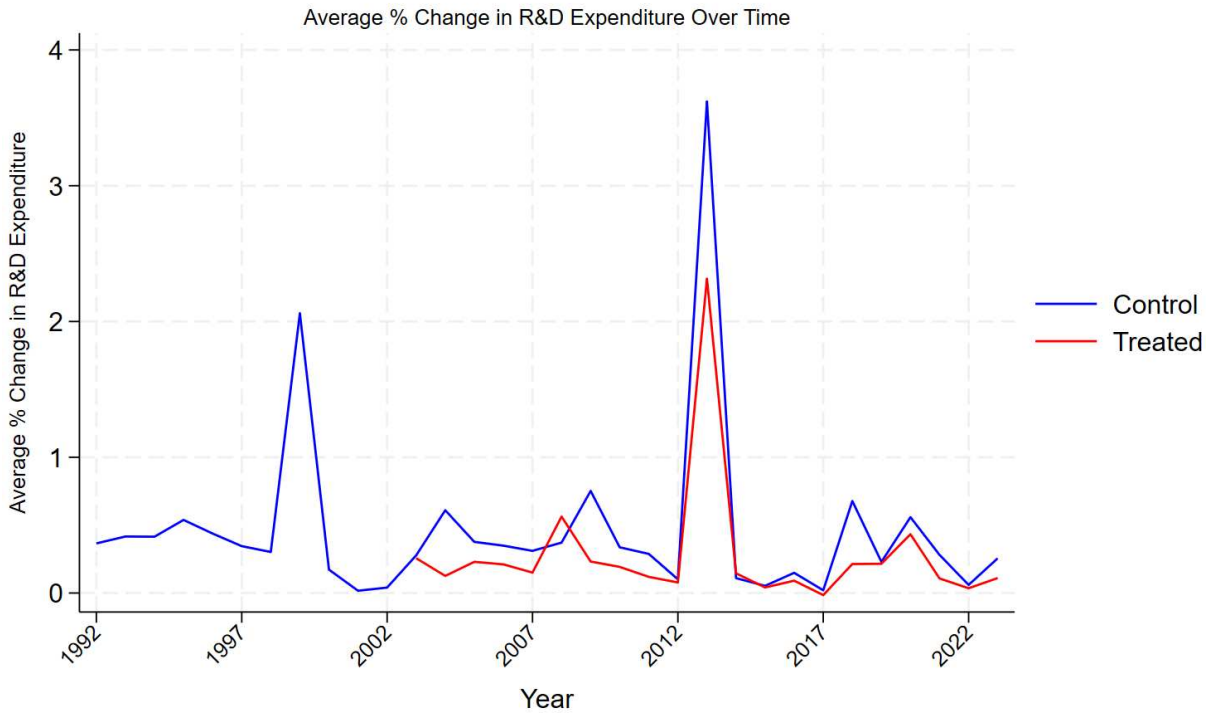

Fig.3. Impact of policy implementation on the average % change in R&D expenditure over time

We analyse the impact of policy adoption by states reported in Table 1 on the R&D expenditure of the targeted firms. Table 3 shows the findings of a DID regression that looks at how the introduction of an e-waste policy affected the R&D expenditure. The coefficient for the policy implementation treatment variable is negative and significant (β=-0.13, $p<0.05$), meaning that, on average, firms in states with e-waste policies experienced a 13% lower

percentage change in R&D intensity than those without such policies. This finding supports H1, which indicates that firms cut back on R&D spending in reaction to changes in resource allocation brought on by e-waste policy requirements.

Table 3

DID regression results: Impact of policy implementation on R&D expenditure

Variable	Coefficient (S.E.)
Treatment (1 vs 0)	*-0.13*** *(0.06)*
No. of control groups	*1559*
No. of treatment groups	*540*
Total observations	*20993*
Fixed Effects	*Present*
Dependent Variable	*%Δ in R&D*

*Note: **p<0.05*

4.2. Impact of policy adoption on marketing expenditure

In order to assess the effect of policy implementation on the marketing expenditures of the targeted firms, we also create a comparison graph between the treatment and control groups. Figure 4 shows the trends in the treated group's (red line) and control group's (blue line) average percentage change in marketing spending over time. The pre-treatment period supports the assumption of parallel trends in the DID analysis. After the policy implementation, the treated group (red) and the control group (blue) diverged over several years, indicating that the policy had an impact on marketing spending. Although there are variations in both groups, the treated group continuously shows lower average increases in marketing spending than the control group. Hence, Figure 4 indicates that in comparison to

control firms, treatment firms' marketing expenditures have been limited by the introduction of e-waste policies. Therefore, the sample analysis supports our H2 and a DID analysis is required to generalize these results for a large group of the population.

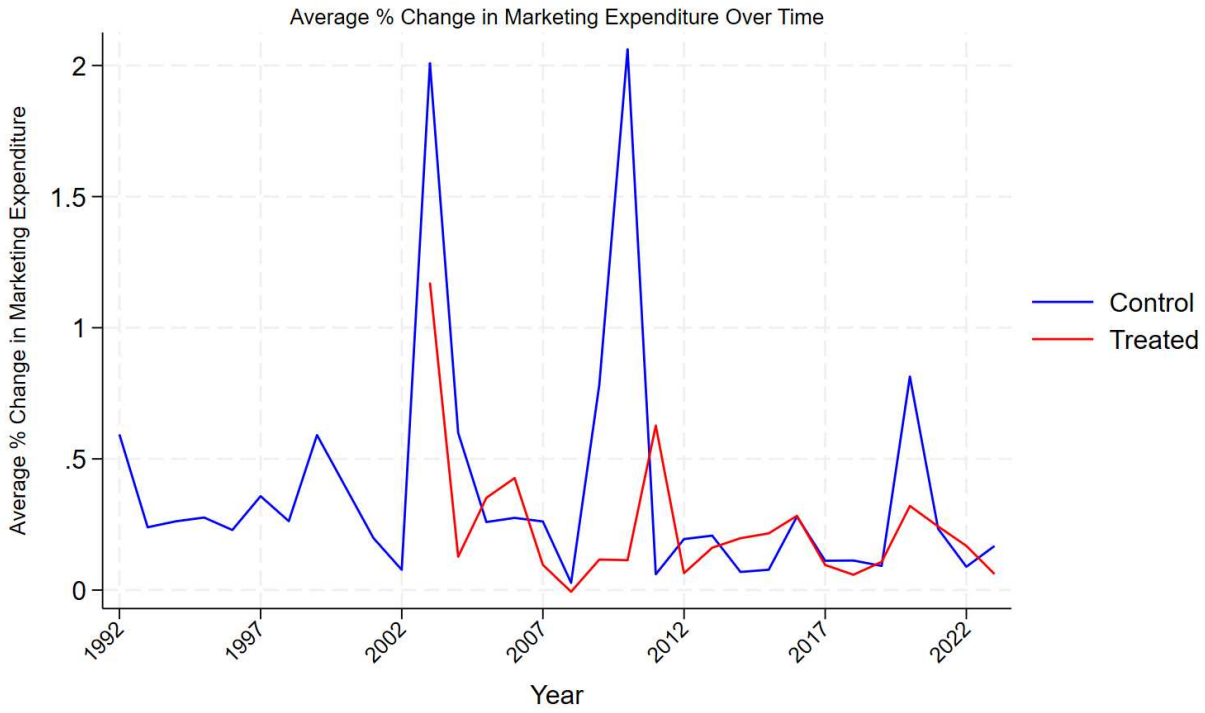

Fig.4. Impact of policy implementation on the average % change in marketing expenditure over time

We examine how state policy implementation affects the targeted firms' marketing budgets. Table 4 presents the DID regression findings by analysing the influence of e-waste policies on marketing expenditure, with an emphasis on the treatment group (targeted firms in states with e-waste laws) and the control group (targeted firms in states without such policies). The coefficient of treatment effect is negative and significant (β=-0.03, $p<0.1$). This implies that following the implementation of the e-waste regulation, companies in treated states spent 3% less money on marketing activities than those in control states. Hence, the results support H2, which suggests that targeted firms face restrictions from e-waste regulations, forcing them to lessen their marketing expenditure.

Table 4

DID regression results: Impact of policy implementation on marketing expenditure

Variable	Coefficient (S.E.)
Treatment (1 vs 0)	*-0.03**
	(0.01)
No. of control groups	*2056*
No. of treatment groups	*612*
Total observations	*27403*
Fixed Effects	*Present*
Dependent Variable	*% Δ in Marketing*

*Note: *p<0.1*

The DID regression results support our hypotheses. We also perform the extended DID analysis to check the robustness of our results.

5. DID extended model for the robustness check

We run an extended DID model for the robustness check. There could be a few firms and state-related factors that can affect R&D and marketing expenditures. Hence, it is crucial to address these issues to strengthen the results. We use an extended DID regression, which is estimated by the below equation:

$$Y_{ist} = \alpha + \beta * Policy_{st} + \gamma * T_s + \delta * P_t + \theta * X_{ist} + \epsilon_{ist} \text{.....(3)}$$

Equation (3) is similar to equation (1), with an additional X_{ist} term representing a vector of firms and state-level covariates. The parameter θ is the coefficient for these covariates. We use prior literature to identify factors that can affect R&D and marketing expenditures. Since inflation has an impact on expenses, income, and general economic dynamics, it can have a big impact on businesses' R&D and marketing expenditures (Graham

and Frankenberger, 2011; Mansfield et al., 1983). R&D projects may become more costly due to rising labour, equipment, and raw material costs, which may cause businesses to prioritise or scale back shorter-term investments. Customers' disposable income is frequently decreased by inflation, which forces businesses to modify their marketing tactics to place more emphasis on affordability and value than on luxury or high-end goods. We collect the annual inflation rate data from Statista and merge the data with our original database. The unemployment rate influences firms' strategies associated with R&D and marketing expenditures because it influences consumer demand, labour costs, and general economic conditions (Ganong and Noel, 2019). High unemployment lowers consumer expenditure, as the market for novel or inventive items is unpredictable, and businesses may reduce their R&D expenditures. In order to save money during times of high unemployment, many businesses reduce discretionary spending, including marketing (Attinasi and Klemm, 2016). We obtained the U.S. unemployment data from Statista and merged it into our original database.

We also collected some firm-related factors that could affect our analysis. Larger firms typically have more resources, established procedures, and a stronger market presence than smaller ones (Wong et al., 2020). Hence, firm size has a considerable impact on R&D and marketing investments. We include a log of total assets as a proxy for firm size following prior literature (Lin and Chang, 2015). Growing businesses typically boost marketing to take advantage of market opportunities and R&D to create new goods. Hence, we include revenue growth percentage in our analysis following prior literature (Lev et al., 2010). We obtain data on firm assets and revenues from Compustat. We merge these two variables' datasets into our original database for analysis. We use wild bootstrap, which is more efficient for robust standard errors, especially in panel or clustered data sets (Gonçalves and Kaffo, 2015). We have a limited number of clusters, and the wild bootstrap works well to prevent the standard

errors from being underestimated, as could happen with traditional methods. This bootstrapping method accounts for heteroskedasticity and within-group correlation, which often leads to biased estimates if not addressed (Davidson and Flachaire, 2008). The robustness results are reported in Tables 5 and 6. Using bootstrap techniques and adding control variables improves the statistical model's accuracy, robustness, and dependability. Better significant results with lower p-values arise from this, enabling more robust inference about the treatment impact. The findings' robustness and trustworthiness are increased by the combination of controls and sophisticated estimating techniques.

Table 5

Extended DID regression results: Impact of policy implementation on R&D expenditure

Variable	Coefficient (S.E.)
Treatment (1 vs 0)	*-0.12*** *(0.05)*
No. of control groups	*1525*
No. of treatment groups	*533*
Total observations	*20584*
Fixed Effects	*Present*
Control Variables	*Present*
Bootstrapping Clusters	*1000*
Dependent Variable	*% Δ in R&D*

*Note: **p<0.05*

Table 6

Extended DID regression results: Impact of policy implementation on marketing expenditure

Variable	Coefficient (S.E.)
Treatment (1 vs 0)	*-0.03*** (0.01)*
No. of control groups	*2007*
No. of treatment groups	*596*
Total observations	*26599*
Fixed Effects	*Present*
Control Variables	*Present*
Bootstrapping Clusters	*1000*
Dependent Variable	*% Δ in Marketing*

*Note: **p<0.05*

6. Discussion and policy implications

6.1 Discussion

This study aims to explore how state-level e-waste recycling regulations affect businesses' strategic resource allocation. Specifically, we seek to assess whether regulatory compliance prompts a shift in resource allocation that could constrain firms' promotional and innovative activities. This research builds on institutional theory, which suggests that organisations conform to institutional pressures-coercive, normative, and mimetic-to maintain legitimacy (Mola et al., 2023). This study helps expand the ongoing conversation about how firms adjust to environmental policies set at the state level. The prior literature focuses more on federal mandates or voluntary environmental initiatives (Du et al., 2024; Scott et al., 2023) and our study shifts the lens to state-level policies and how they shape company strategies.

Our analysis is focused on those firms which are associated with various stages of the electronic equipment lifecycle. According to *Hypothesis 1*, firms reduce their R&D

expenditures when e-waste policies are enacted. The results, supported by a difference-in-differences (DID) approach, show that firms in states with such regulations redirect resources away from innovation toward compliance-related activities. Businesses in states with e-waste laws invested less aggressively in R&D following the implementation of e-waste policies. This supports the notion that coercive and normative institutional pressures significantly influence strategic resource allocation (Duan et al., 2025; Xu et al., 2023). Firms prioritize adherence to environmental standards and regulations, often involving costly supply chain adjustments and product redesigns aimed at enhancing recyclability at the expense of long-term innovation.

In line with *Hypothesis 2*, we find that e-waste regulations are associated with a reduction in marketing expenditures. Firms may perceive compliance as a substitute signal for environmental responsibility, reducing the need to invest heavily in marketing to build credibility. This behaviour reflects mimetic pressures, where firms model their behaviour on peers who use compliance to demonstrate legitimacy (Beddewela and Fairbrass, 2016; Gonsalves, 2023). These findings add to research on green marketing and legitimacy signalling (Hossnofsky et al., 2025; Waites et al., 2020).

Furthermore, the discussion places e-waste regulations within the principles of the circular economy, which promotes sustainability, recycling, and efficient resource use (Fatima et al., 2024; Song et al., 2019). However, the observed decline in R&D spending raises concerns: while these laws promote compliance and environmental responsibility, they may inadvertently hinder the development of innovative technologies that are essential to advancing circular economy goals. This study contributes to the literature by demonstrating how state-level environmental policies, framed through institutional theory, shape corporate resource allocation strategies and may create tensions between short-term compliance and long-term innovation.

6.2 Implications

Our study advances institutional theory by presenting empirical insights on how institutional pressures impact firms' resource allocation strategies. In particular, it emphasises how businesses give compliance with state-led e-waste regulations as a first priority, changing their strategic choices on R&D and marketing spending. This emphasises how important social and regulatory expectations are in influencing organisational behaviour, even when doing so comes at the price of long-term innovation or external signalling initiatives. The results show a substantial trade-off between strategies that prioritise innovation and resource allocation that is driven by compliance. This study contributes an additional insight into the institutional theory that meeting compliance demands can sometimes hold companies back from investing in breakthrough R&D. It offers a framework for understanding how organisations balance immediate regulatory demands with long-term priorities, bridging the gap between external pressures and their unintended impacts. We examine the signalling behaviour within institutional theory through the demonstration that compliance with e-waste regulations conveys legitimacy to stakeholders. This advances the theoretical understanding of signalling theory by demonstrating how stakeholders' expectations can be met by compliance alone, reducing the need for extra marketing or promotional initiatives. It supports the notion that legitimacy obtained via following rules might serve as an alternative to expensive external signalling systems. Our study combines institutional theory with circular economy and emphasises how e-waste regulations serve as coercive tools that push businesses towards environmentally friendly operations and support the goals of the circular economy. This link provides a comprehensive understanding of how policies influence compliance behaviours as well as sustainability transitions by bridging institutional theory with sustainable frameworks.

Managers need to recognise the trade-offs that come with adherence to e-waste regulatory requirements. Although legitimacy depends on compliance, it may take resources away from marketing and R&D. Managers can balance resource allocation and regulatory compliance to improve recyclability and product differentiation. While staying committed to R&D, managers should look for ways to meet regulatory objectives. To meet e-waste regulation requirements and assist in spreading the cost of innovation; for example, partnerships with industry consortia or research institutes should be used. Although compliance naturally conveys credibility, managers can go above and beyond the call of duty to gain a competitive edge. By making greener products or improving sustainability, firms can enhance brand reputation and appeal to a growing segment of eco-conscious customers. Since stakeholders already see compliance as a sign of credibility, managers should reconsider the need for extensive marketing efforts to signal compliance. By redirecting marketing efforts to highlight innovation or unique value propositions, firms can reinforce their brand identity beyond the baseline of regulatory compliance. To take advantage of new market opportunities, managers should match their plans with the circular economy's tenets. Designing products with longevity, adaptability, and recyclability in mind supports regulatory adherence and also draws in eco-aware customers and eventually lowers production costs.

7. Conclusion

7.1 Conclusion

We analyse the influence of e-waste policies on corporate strategies associated with R&D and marketing activities. Drawing on three decades of data and DID analysis, we found that firms operating in states with these policies tend to scale back on R&D and marketing efforts as they shift their focus towards meeting regulatory requirements. While prior studies mainly focus on e-waste regulation effects on the environment, our study offers a novel

insight by analysing their effects on corporate budgeting decisions across various sectors. We add value by combining insights from institutional and signalling theory to account for this firm's behaviour. Firms comply with e-waste rules not just due to regulatory demands but also serve as a strong indicator of environmental legitimacy. With compliance now mandatory and transparently measurable, firms have less need to invest heavily in marketing to prove their environmental commitment. Similarly, the pressing demands of regulatory compliance limit firms from investing in R&D. Our findings make a novel contribution to the literature by demonstrating that regulatory pressures lead firms to reprioritise their internal resource allocation. Our research emphasises that managers must carefully align regulatory obligations with the pursuit of sustainable competitive advantage.

7.2 Limitations and future research directions

This study uses panel data, which may not fully reflect complex consumer attitudes, beliefs, and behaviours surrounding the recycling of e-waste but offers insightful information about the relationships over time. The consumer-side dynamics that impact and are impacted by e-waste legislation may be overlooked by longitudinal data, which usually concentrate on firm-level measures. Researchers can conduct primary survey data analysis to gain deeper insights into public perceptions of corporate adherence to following regulations and acting sustainably. They can divide up the consumer base according to demographics, environmental consciousness, and purchase patterns to comprehend the disparate effects of e-waste policies. They can perform cross-cultural studies, which can provide insight into how various cultural and societal norms affect recycling practices. Future studies can also perform sector-wise analyses to gain additional insights into this research area. A mixed-methods approach, including qualitative interviews and secondary data analysis, will provide deeper insights into the decision-making procedures of businesses under regulatory pressure. We provide the analysis and findings in the context of developed countries. Researchers can perform the

same analysis for developing nations and compare the results. This comparison provides additional insights related to government regulatory policies and their impact on firms' resource allocation strategies.

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