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Circular economy and public policies: A dynamic analysis for European SMEs

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Abstract

Previous empirical studies have highlighted the importance of the institutional framework in fostering a transition towards the circular economy (CE). Adopting a dynamic approach, which merges three Flash Eurobarometer surveys conducted in 2015, 2017 and 2021 into a single dataset, we observe the evolution in the factors determining the adoption of CE practices. Firstly, using factor analysis, our results indicate two groups of institutional drivers: knowledge and environmental spillovers. Secondly, applying a multivariate probit model, we observe that both spillovers have a positive effect on the adoption of the CE. Finally, we find that the effect of knowledge spillovers remains relatively constant, while that of environmental spillovers tends to increase. This suggests that firms are increasingly benefiting from the adoption of circular practices by their peers. Policymakers should take into account that a more intense knowledge spillovers and a stronger institutional framework will increase the likelihood of European small- and medium-sized enterprises (SMEs) adopting CE practices.

KEYWORDS
circular economy, European SMEs, institutional framework, knowledge spillovers, public policies

1 | INTRODUCTION

The circular economy (hereafter CE) has emerged as a significant concept for the transformation of economic production and consumption models from the classical 'take-make-use-dispose' towards circular systems, in which the objective of business models is to eliminate all types of waste (Demirel & Danisman, 2019). The implementation of the CE can contribute to achieving the United Nations Sustainable Development Goals, particularly Goal 12 'Responsible Production and Consumption.' To this purpose, the European Union's (EU) Circular Economy Action Plan for (2020) set ambitious goals for transitioning to a stronger CE, in which obsolete materials and goods are regenerated to reduce waste, close the production-consumption loop, and slow product replacement.

However, the pattern of adoption of CE actions differs among countries and sectors (Robaina et al., 2020) because of several factors. The various Flash Eurobarometers conducted by the European Commission have added to studies analysing both internal (resources and capabilities) and external (access to knowledge, financial sources, public aid and regulation) factors that affect the decision to adopt CE strategies (Horbach et al., 2012; Kiefer et al., 2019). Previous analyses show that governmental regulations are a primary force in promoting

Abbreviations: CE, circular economy; CEAP, Circular Economy Action Plan; CEI, CE innovations; EC, European Commission; EU, European Union; R&D, research and development; SMEs, small- and medium-sized enterprises.

environmental innovations (Rennings & Zwick, 2002).[1] However, the institutional framework linked to a firm's environment (push and pull effects such as public investment in environmental science, subsidies to innovative firms and the population's environmental awareness) has scarcely been considered in empirical analyses. Its change over time is even less studied.

Our starting point for an attempt to fill this gap is the concept that the forces promoting the transition from the linear model to the CE operate at individual, collective and institutional levels (Azevedo et al., 2017; Zhu et al., 2022). Our main database sources are three Flash Eurobarometer surveys (FL426, FL456 and FL498), which give a representative sample of European small- and medium-sized enterprises (SMEs).[2] The final dataset consists of 26,361 SMEs across 27 European countries, broken down into waves 2015 (8,175), 2018 (8,363) and 2021 (9,823).

We have several findings. First, by factoring five indicators from the Eco-Innovation Index, which measure the environmental innovation performance of EU Member States (Al-Ajlani et al., 2022), we obtain two institutional drivers. One captures the knowledge spillovers that push the adoption of CE actions by European SMEs, such as public and private investment on green research and development (R&D) and aggregate eco-innovation outcomes. The other captures the environmental spillovers related to the efficiency gains from a better management of water, energy and materials, as well as the weight of eco-industries in terms of value-added, employment and exports. This initial step facilitates the analysis of the relationship between institutional forces and the adoption of CE practices by European SMEs from 2015 to 2021.

Second, applying a multivariate probit model, our results show that public policies generating knowledge and environmental spillovers have a positive and significant effect on the adoption of CE activities. On one hand, the effect of knowledge spillovers remains relatively constant over the period 2015–2021. On the other, the positive environmental spillovers have a clear and growing effect over time on the adoption of reducing and recycling activities but is neutral when considering the redesign of products. Additionally, while reducing requires the lowest investment effort (they are more closely related to management, and organisational changes), recycling and redesigning, being more complex activities, require a more intensive effort.

Our main contributions are the following. First, most of the existing empirical evidence associates a firm's ability to perform CE activities with its characteristics, or the nature of the sector in which it operates. However, aspects related to the institutional framework being driven by governments and other socioeconomic agents have been ignored. Despite the CE being envisaged as a complex process between different agents, few studies consider the adoption of CE practices to be a subject of multilevel drivers. In this regard, Garrido-Prada et al. (2021) at empirical level, and Zhu et al. (2022) at theoretical level are two exceptions. This paper contributes to the empirical literature by showing how different institutional factors can be grouped into two categories of spillover, knowledge and environmental. Our results demonstrate the importance of institutional spillovers in transforming a firm's decision to adopt CE practices. Hence, the study offers insights into the nature of institutional forces affecting SMEs' engagement in the CE, as well as their policy implications.

Second, our empirical work addresses the adaptative interrelations among CE initiatives. This idea is closely related to Zhu et al. (2022). At an empirical level, the lack of consistent panel information has led to a gap in the literature analysing the temporal dimension of CE drivers. In line with the evolutionary theory, a firm's ability to adopt CE measures depends on to two types of learning. On the one hand, the implementation of a specific measure can be facilitated by the experience generated internally by the firm or adopted from the external environment ('temporal learning'). On the other hand, the probability of carrying out a certain action can be linked to the learning facilitated by the implementation of certain CE measures ('experimental learning'). In this regard, previous works ignore that the adoption of certain CE measures is conditioned by the experience and the development of specific dynamic economies that ease the adoption of more general measures (Zamfir et al., 2017).[3] This paper provides evidence of the dynamic nature of the interrelationships in the adoption of CE practices.

Finally, despite the great interest of institutions and governments in promoting the transition to CE among firms, the diversity of actions covered by the concept of CE increases the complexity of identifying which drivers enhance or hinder their adoption by a firm. This paper contributes to policymakers by defining the main institutional factors driving firms' adoption of CE practices. While some of them may be more closely related to the generation and diffusion of knowledge, the others are related to the positive impact that more environmentally sustainable practices may have on the economy. In deploying their array of policies, the policymakers need to be aware of the importance of both spillovers.

The remainder of the paper is structured as follows. The following section describes the main literature review on CE, public policies and SMEs and presents the main research questions. Section 3 presents our main databases and the explanatory variables. The following section describes the empirical methodology. Section 5 presents our main results. Our concluding section presents the most relevant conclusions and implications.

2 | LITERATURE REVIEW AND RESEARCH QUESTIONS

2.1 | The circular economy and SMEs

The concept of CE was first used in the literature by Turner and Pearce (1990) and has gained increasing interest from both public

[1]This is known as the 'regulatory push/pull effect' (Rennings, 2000).

[2]The three Flash Eurobarometers are entitled 'Small and Medium Enterprises, Resource Efficiency and Green Markets'. These data were collected in September 2015 (FL426); September 2017 (FL456); and between November and December 2021 (FL498).

[3]Teece et al. (1997) describe the transformative capacities of firms in terms of dynamic capabilities, where 'dynamic' refers to the capacity to renew competencies and activities to achieve a better fit with the changing business environment.

and private institutions. The term is considered complex and challenging since it requires the commitment of consumers, firms and markets. Additionally, it is a multidisciplinary approach where various disciplines interact—Engineering, Economics, Politics and Environmental Sustainability all contribute to its development (Bag et al., 2022). As a result of recent developments in the field of CE, a range of studies have focused on explaining it as a paradigm, its relationship with sustainable development, and the many concepts that go into its definition (Geissdoerfer et al., 2017). Furthermore, academia, industry and policymakers adopted these ideas quickly when implementing regulatory initiatives to improve resource use and waste management (Fitch-Roy et al., 2021).

The CE transition aims at reducing the problems related to climate change, scarcity of resources, pollution, waste management and fossil fuel dependence over the entire life cycle of products (Horbach & Rammer, 2020). The CE was initially associated with the imperatives of the 3Rs (reduce, reuse, recycle), which are fundamental for the waste management process (Kirchherr et al., 2017; Liu et al., 2017; Manickam & Duraisamy, 2019). Its evolving understanding introduced a new series of imperatives, the 6Rs 'reuse, reduce, recycle, redesign, refurbish and repurpose' (Reike et al., 2018), a 9Rs framework 'rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover' (Potting et al., 2017) and then the 10Rs 'refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recovery' (Morseletto, 2020). In essence, the CE transition replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes.

The CE model thus tries to overcome the traditional linear pattern of production and consumption.[4] Following this line of analysis, CE aims to transform goods that are at the end of their useful life into resources for others, 'closing the loops' in industrial ecosystems and minimising waste. Additionally, it tries to slow product replacement cycles despite the fact it demands a more fundamental change than closing the loops. According to Bag et al. (2022), many firms are still following decades old practices of cutting costs and minimising raw material stock levels, as well as eliminating flexibility during such processes, which can make the firm more vulnerable in the CE.

This new paradigm provides by providing entrepreneurial opportunities and generating green jobs in various fields (Korhonen et al., 2018; Winans et al., 2017). SMEs, as central actors in the transition towards a sustainable production model (European Commission, 2020),[5] may benefit from several opportunities such as increased image, cost reduction, business growth, higher productivity, environmental recovery through reduced CO2 emission and greater sustainability. Studies show that the adoption of CE principles can have benefits for firms that far outweigh their costs (Dey et al., 2022; Patwa et al., 2021).

Despite efforts at the different institutional levels, European SMEs continue to find many difficulties in improving resource management throughout the product life cycle. Recycling is complicated for SMEs since it requires the availability of high-quality materials and more efficient recycling technologies, while sustainable design requires considerable technological and financial capacities. Consequently, SMEs respond to external pressures that may affect to the decision to innovate; these include compliance with the law, social pressure on environmental commitment and green economic incentives, and the influence of personal determinants (Centobelli et al., 2021; Luthra et al., 2022; Ormazabal et al., 2018).

Additionally, SMEs perceive different obstacles that reduce their capacity to adopt CE practices. The main reasons are related to lacks such as financial support, adequate information management, proper technology, technical resources, public support, qualified professionals, organisational commitment and access to a broader ecosystem of suppliers and providers (Garcés-Ayerbe et al., 2019; Ghisetti & Montresor, 2020; Ormazabal et al., 2016; Prieto-Sandoval et al., 2018; Ritzén & Sandström, 2017; Rizos et al., 2016). All these characteristics result in SMEs' absorptive and internal capabilities to carry out CE practices being lower than those of large firms. Such obstacles, together with unclear regulations, bureaucracy, limited guidelines, cost barriers and lack of support from public institutions (Mura et al., 2020; Ormazabal et al., 2018), hamper the implementation of the required changes (Garcés-Ayerbe et al., 2019).

Consequently, the adoption of CE practices by SMEs depends on multiple factors (Marino & Pariso, 2021; Prieto-Sandoval et al., 2018). To facilitate this process, the European Commission has introduced both legislative and non-legislative measures to promote the adoption of sustainable practices by SMEs.

2.2 | Public policies to promote the adoption of CE practices

The adoption of CE practices requires firms to carry out CE innovations (hereafter, CEI) that are characterised by inherent costs and risks (Masi et al., 2018).[6] The whole concept has recently been proposed as the dynamic symbiosis between eco-innovation and CE (Scarpellini et al., 2020; Triguero et al., 2022). CEIs conducted by firms, thanks to the use of circular management practices, bring benefits not only to innovative firms but also to society. As a result, CEIs are subject to the so-called 'double externality' since they have standard knowledge

[4]A linear model is characterized by a unidirectional flow of materials, from which raw materials are transformed into products and, ultimately, into waste. This linear approach to production and consumption processes does not consider the environmental burdens and natural limits to economic growth resulting from climate change because of increasing greenhouse gas emissions and the depletion of non-renewable resources (Pichlak & Szromek, 2022).

[5]According to the European Commission (2020) 'Entrepreneurship and Small and medium-sized enterprises (SMEs)', in 2020 SMEs represented approximately 99% of all businesses, employed around one hundred million people, and generated more than half of European GDP.

[6]Eco-innovations not only support sustainable and efficient processes but can equally trigger new CE business models by providing novel logistics and technical infrastructures (De Jesus & Mendonça, 2018). CEIs present common characteristics to eco-innovations. They include reducing the use of energy, water and materials, and attenuating the emission of polluting substances (Horbach et al., 2012). CEIs can be defined as the innovation activities "*related to the use of cleaner and more efficient processes, material recycling, water management processes, and eco products that reduce environmental impact and maximize resource efficiency*" (Triguero et al., 2022).

and environmental spillovers (Rennings, 2000). This double externality appears because, on the one hand, CE innovators are unable to fully appropriate the value created, as knowledge spillovers can benefit other firms. CE innovators produce important positive externalities like a strongly reduced environmental footprint. On the other hand, as these benefits are appropriated by society rather than by the firms that invested in circularity technologies, conventional market failures arise. Hence, CEIs are more difficult to manage, and this increases the chances of technological lock-ins and path-dependency at the advantage of dirtier (more established) technologies (Cecere et al., 2014).

To facilitate the transition, policymakers deploy public policies to promote the reduction of the use of non-recoverable resources, improve waste management, and the development of eco products (Pichlak & Szromek, 2022).[7] These public interventions involve areas such as innovation, industry, education, employment and international trade (Kautto & Lazarevic, 2020). The European Commission's commitment to CE has resulted in the development of different plans. First, the European Commission in December 2015 proposed an Action Plan for the CE to encourage SMEs with the objective of 'closing the loop' of product lifecycles (Cainelli et al., 2020). In 2018, the European Commission defined a framework to monitor the implementation of the CE concept in member countries, which consists of 10 indicators covering different thematic areas: production and consumption, waste management, secondary raw materials, competitiveness and innovation (European Commission, 2020). Later, in March 2020, the European Commission adopted the new Circular Economy Action Plan (CEAP) 'For a cleaner and more competitive Europe'. The CEAP emphasised that the EU alone cannot deliver the ambition of the European Green Deal for a climate-neutral, resource-efficient, and CE.

A wide range of empirical works show the direct influence that public policies exert on the adoption of CE practices by SMEs (Garcés-Ayerbe et al., 2019; García-Quevedo et al., 2020; Garrido-Prada et al., 2021; Ghisetti, 2017; Triguero et al., 2022). However, few works explore the incidence of public policies to generate a particular institutional framework at country level that exerts on a firm's adoption of CE practices. The deployment of these initiatives requires the commitment and cooperation of numerous actors, including governments (Diercks et al., 2019), the coordination between regulations at EU, national, regional and local level (Mura et al., 2020) and the collaboration of firms and trade unions at sectoral level (Costa-Campi et al., 2015) to reduce the regulative uncertainty perceived by SMEs.

This approach responds to the conceptualisation of CE transition at three levels by Kirchherr et al. (2017), Dey et al. (2020) and Zhu et al. (2022).[8] At the micro level, firms must adapt their operation, performance, decision-making and strategic choices. At the meso level, firms interact with their competitors, institutional agents and a broader set of contextual factors, such as market and user-level changes in technology and investments in science and culture (Ormazabal et al., 2016). Finally, at the macro level, SMEs are influenced by global and national changes where policymakers must facilitate the most appropriate regulatory framework. Here, we adopt this approach by considering not only the factors affecting directly to a firm's decision to adopt CEIs, but also the influence of public policies at national level and also the influence of different agents composing the economic and knowledge context.

According to the institutional theory, public policies influence the adoption of CEIs through three different pressures: coercive, normative and mimetic. Coercive pressures respond to government intervention such as tax cuts, public education, awareness creation programs and pilot schemes (Alonso-Almeida et al., 2020). Normative pressures correspond to the drafting of suitable standards and the creation of a technology-friendly environment. Mimetic pressures come from competitors adopting CE practices and gaining substantial benefits that will create pressure on their peers (since competitors with tangible resources to develop CE practices can gain a competitive advantage and easily outperform other firms in the industry). It has been shown that different policy instruments play different roles in driving firms to invest in several types of eco-innovations (Triguero et al., 2013). Several authors emphasise that governmental intervention can be a driver of CEIs, but the comparative advantage of specific policies remains unclear (Cainelli et al., 2020; De Jesus & Mendonça, 2018; Garrido-Prada et al., 2021).

2.3 | Effects of public policies and spillovers on the adoption of CE

Public policies influence directly a firm's decision to develop CE practices, but they also devote financial resources to universities, research centres and industry–university collaboration. These public resources encourage the development of R&D and eco-innovations in their first stages of the path that connects science, technology and innovation. This generates a pool of public knowledge and a new institutional framework that gives as a result knowledge spillovers and a change of the rules of collaboration among different agents. Firms will capture these knowledge spillovers, which increase their capability to adopt new CE practices. Therefore, public R&D investments generate knowledge spillovers positively influencing SMEs' CE investments (Jaffe et al., 2005), since they provide cost-free exploitable knowledge for firms (Edler & Fagerberg, 2017).

Figure 1 shows our conceptual model. On the one hand, we consider governments' efforts to promote the generation of knowledge relevant to developing CEIs by firms, universities and technological centres. We assume that the conditions in which SMEs attempt to undertake these actions are subject to the capacity of other firms to create an adequate environment (Horbach, 2008; Jové-Llopis & Segarra-Blasco, 2018). On the other hand, at the firm level, we consider various internal and external factors that determine firms' ability to develop CEIs that have been extensively covered in the literature

[7]The EU-27 R&D public expenditure was 109.25 billion euros in 2021, of which 2.59% was directly spent on the environment.

[8]Kirchherr et al. (2017) define CE as "an economic system that is based on business models, which replace the 'end of life' concept with reducing, alternately reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro, meso and macro level".

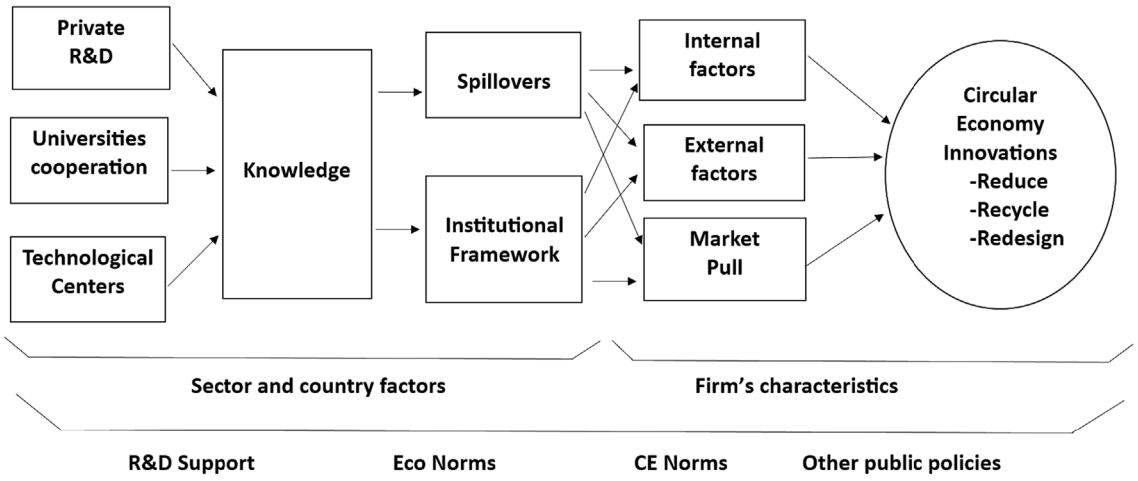

FIGURE 1 Drivers and barriers to CEI at the firm level. *Source: own elaboration.*

(among others the access to financial resources, internal knowledge and international experience).

Therefore, the ability to move towards a CE is subject to a whole network of public policies that aim to develop relevant knowledge and enhance the innovative ecosystem, which allows firms to adopt more efficient management methods. Here, the actors that adopt CE actions benefit primarily from the efforts previously made by other agents eco-innovating at different levels.

Our model is like Garrido-Prada et al. (2021), who analyse the impact of public environmental and energy R&D on CE implementation and investment by European SMEs. Garrido-Prada et al. (2021) show how public policies promote knowledge spillovers and changes in the institutional framework that, thanks to the absorptive and learning capacity of firms, have indirectly fostered CE practices through changes in research institutions and the innovation system. Their results confirm that knowledge generated by public funding positively affects SMEs' implementation of CE activities. As previously stated, these knowledge spillovers are particularly important for developing eco-innovations (Cainelli et al., 2011; De Marchi, 2012; Horbach, 2016) since these constitute a new (as compared with traditional and more established innovation) fields and are more dependent on external sources of information and on basic research activities.

Therefore, CE practices may require knowledge and skills that do not belong to the core competences of firms (Teece et al., 1997). Thus, we assume that the adoption of CE practices is influenced by both the external knowledge generated by public policies and by the innovative environment. The influence of the mimetic, normative and the coercive pressures that governmental interventions exert on firms' behaviour are crucial to achieve this CE transition. We propose that public policies exert a heterogeneous impact across different CE typologies through the generation of spillovers and the influence in the institutional framework. Therefore, our first research question is:

> **RQ1.** What is the impact of public policies on firms' adoption of CE practices? Are there differences depending on the CE typology?

The adoption of CE practices depends on a firm's learning capability, which is the ability to acquire and accumulate knowledge. Organisational learning is an iterative and dynamic process in which firms engage in experiences, draw inferences from them and store the inferred material for future experience. The learning capabilities facilitate SMEs to accelerate the adoption of CE practices over time thanks to their accumulated internal learning but also thanks to the knowledge spillovers generated by their peers. Different theories and models have tried to explain how these 'temporal learning' among different agents evolves over time. In this sense, new knowledge, ideas and practices is derived from a niche group of innovators. This new knowledge spreads to the socio-technical regimes and finally it shapes into a sound practice (Geels, 2002).

This continuous flow of knowledge at multilevel (from research centres, universities, industrial sector, firm level and society) has as a result an evolution of firm behaviour and the whole system. Hence, SMEs will develop CEIs thanks to their accumulated knowledge and the one acquired from the external environment. Over time, their capacity to learn will evolve thanks to their accumulated experience. Consequently, public policies manifested by spillovers and institutional framework will increase over time their influence on a firm's ability to adopt CE practices. In this sense, the 'temporal learning' responds to an evolutionary approach like Zhu et al. (2022). Therefore, our second research question is:

> **RQ2.** Do public policies have a different influence over time?

Additionally, the literature points out the existence of certain interdependencies in the adoption process (Cainelli et al., 2020; Garcés-Ayerbe et al., 2019; Katz-Gerro & Lopez Sintas, 2019; Triguero et al., 2022). These results suggest the existence of 'experience learning', which refers to the ability to acquire and accumulate knowledge by the development of other CE practices. For instance, Garcés-Ayerbe et al. (2019) explore the temporal implementation of CE practices by European firms. Their findings show a gradual

implementation of CE practices. They identify three stages: 1) implementing material recycling and reuse measures, 2) using measures to minimise power consumption and improve product design and 3) the most proactive SMEs are applying measures to rethink water use and turning to renewable energy. Other authors such as Katz-Gerro and Lopez Sintas (2019) demonstrate that European SMEs are likely to undertake waste minimisation, replanning of energy use and redesigning product and services, using renewable energy, and water usage in descending order.

Therefore, more experience in adopting new CE practices improves a firm's performance and reduces its costs of implementation. As a consequence, learning curves arise when firms continuously undertake and activity and they extend their practices towards a wider number of CE practices. In empirical studies to date, this 'experience learning' is assumed to be constant across time. In line with Zhu et al. (2022), we assume that 'experience learning' also may exhibit certain dynamics. Therefore, our final research question is the following:

> **RQ3.** Do interrelationships between CE practices exhibit temporal dynamics?

3 | DATA AND DESCRIPTIVE STATISTICS

3.1 | Data sources

When we try to understand how European SMEs undertake the transition towards CE, it is desirable to adopt a temporal perspective. However, to the best of our knowledge, none of the literature has adopted this approach. This absence is likely due to the cross-sectional nature of surveys related to the adoption of CE measures at the firm level. The EC has conducted several waves of Flash Eurobarometer surveys on the CE, resource efficiency and green markets. These surveys provide representative coverage of European SMEs, allowing for the differentiation of EU state members. In general, although the domain and samples varied in each wave, the questionnaires' criteria and the representativeness of the sample remain identical.

Our main data source contains information from three Flash Eurobarometer surveys on the CE, resource efficiency and green markets. The three surveys correspond to FL426 (collected between 1.09.2015 and 18.09.2015), the FL456 (between 11.09.2017 and 26.09.2017) and the FL498 (between 8.11.2021 and 10.12.2021).[9,10] These Eurobarometer surveys were sent to managers of firms with one to 250 workers in the 28 EU Member States to obtain their opinion on issues related to resource efficiency and the CE. Merging the three waves allows us to observe the changes in the drivers and the obstacles that determined the performance in CE activities of European SMEs in the retail (NACE categories G), manufacturing (NACE categories C) and industry sectors, (NACE categories B, D, E, F). Note that individual firms cannot be identified in each sample. Thus, we do not know whether they are present in all three samples. Consequently, we treat the joint dataset as a sum of three different cross-sections and analyse the heterogeneous behaviours between the three different waves. The introduction of country and year fixed effects indirectly and partially approaches the effects of unidentified individual heterogeneities. The numbers of observations in each wave are 8,173 in 2015, 8,363 in 2018 and 9,823 in 2021, a total of 26,361 observations that provide sufficient information to obtain robust outcomes in each subsample.

Among other topics, the survey also provides a set of internal and external factors that promote resource efficiency, the barriers encountered by the firms involved, as well as a vector of individual characteristics that largely explains the heterogeneity in the adoption of resource efficiency and CE measures. Although some degree of sampling error is present in all surveys, the Flash Eurobarometer guarantees key aspects such as randomness, balance and representativeness. Furthermore, in the methodology, we explain the treatment of some dimensions and the dependent variables to obtain the most efficient estimator.

Additionally, we include the Eco-Innovation Indexes from the Eco-Innovation Scoreboard.[11] This allows us to perform a factor analysis (see Subsection 4.1) of the institutional drivers that represent the spillovers generated at country level. While the Flash Eurobarometer surveys capture the influence of external factors on a firm's decision, they are not able to capture the whole eco-innovation environment. Therefore, these factor variables reflect the innovative environment and the public interventions aimed at promoting CE performance in European firms. The indicator is based on 16 sub-indicators that are grouped into five areas: eco-innovation inputs (public and private investment of R&D and human and financial capital in eco-innovative activities); eco-innovation activities (presence of firms active in eco-innovation); eco-innovation outcomes (patents, research papers in environmental disciplines and their media coverage); resource efficiency results (resource efficiency and GHG emissions intensity); and socioeconomic results (green exports, labour and value added). All these variables allow us to capture regional variations among European countries in terms of the adoption, efficiency and promotion of green markets.

3.2 | Variables

To take advantage of all the information available in the three FL questionnaires, we adopted the approach proposed by Potting et al.

[9]The last year of the sample being 2021 cannot cover the most recent CE policies, economic conditions and consumer behaviour, but is sufficient to identify how past policies and socio-economic tendencies affect the adoption of CE practices at the firm level, thus providing relevant evidence for present and future practices.

[10]Surveys prior to 2015 were considerably different from those ones analysed in this research. Consequently, their introduction would limit the scope of our approach.

[11]Eco-innovation Scoreboard and Eco-Innovation Indexes measure the environmental innovation performance of EU countries. The eco-innovative progress of each European member is based on 16 indicators grouped into five thematic areas: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency and socio-economic outcomes.

TABLE 1 Definitions of variables.

Dependent variables (CE actions)	
	Dummy equal to 1 if a firm …
Reduce	… reduces the use of water, energy, materials or waste.
Recycle	… recycles by reusing materials or waste inside and outside the firm and uses renewable energy.
Redesign	… redesigns its products to be more sustainable.
Independent variables	
Internal factors	
Financial capabilities	Dummy equals to 1 if the manager states that …
Technological capabilities	… the firm relies upon its financial resources to be more resource-efficient.
	… the firm relies upon its technical expertise to be more resource-efficient.
Low financial effort	Dummy equals to 1 if a firm invests.
High financial effort	… up to 5% of the annual turnover per year to be more resource-efficient.
	… more than 5% of the annual turnover per year to be more resource-efficient.
External factors	
Public financing	Dummy equals to 1 if a firm uses …
Public assistance	… public funding (grants, guarantees or loans) in its efforts to be more efficient in the use of resources.
Private financing	… public assistance in its efforts to be more efficient in the use of resources.
Private assistance	… private funding in its efforts to be more efficient in the use of resources.
	… private assistance in its efforts to be more efficient in the use of resources.
Barriers to adopt CE	
Lack of resources and capabilities	Dummy equals to 1 if a firm has faced an obstacle to more efficient activities related to …
	… lack of own resources and capabilities.
Administrative and legal	… environmental legislation.
Cost regulations	… high cost of environmental actions.
Control variables	
National markets	Dummy equals to 1 if a firm sells its green products …
International markets	… in the national market over the past two years.
	… in external markets over the past two years.
Age	Firm age in years.
Size	Number of employees.
Sector	Dummy variable identifying the main activity of a firm: Retail (NACE categories G); manufacturing (NACE category C); industry (NACE categories B/D/E/F)

Source: own elaboration.

(2017). The three questionnaires consider eight or nine actions related to the CE transition. In line with previous studies that address the drivers and obstacles of European SMEs to improve their environmental efficiency, (García-Quevedo et al., 2020; Triguero et al., 2022), we clustered the nine CE actions into three CE practices: (1) reduce materials and energy; (2) recycle materials and reduce waste; and (3) redesign more sustainable products.[12]

In line with the prevailing framework on the drivers that enhance the eco-innovations at firm level, we distinguish between internal and external factors that encourage the adoption of CE actions (García-Quevedo et al., 2020; Horbach, 2008; Triguero et al., 2022). Table 1 defines our main variables.[13] The vector of internal factors captures a firm's financial and technological capabilities to be more resource efficient. In addition, we consider a firm's financial effort to allocate part of its annual turnover to be more resource efficient.

The vector of external factors includes the use of public and private external funds; technological assistance through public channels and technical assistance provided by private firms. In addition, we identify a set of barriers related to the lack of resources and capabilities for European SMEs to adopt CE actions, the difficulties of adapting to administrative requirements and environmental legislation and, finally, the high financial cost of environmental action. Firms developing activities to increase their resource efficiency will probably perceive these barriers more intensely.

Finally, to correct the effects of high heterogeneity among SMEs, we include a set of control variables related to the geographical scope

[12]Flash Eurobarometer 2015 and 2018 in response to the question '*What actions is your company undertaking to be more resource efficient?*' offers the following options: saving water, saving energy, using predominantly renewable energy, saving materials, minimising waste, selling your residues and waste to another company, recycling by reusing material or waste, designing products that are easier to maintain, repair or reuse; while FL 2022 introduces the action 'switching to greener suppliers of materials.' Here, 'reduce' includes saving water, energy, materials, and waste; 'recycle' includes the use of renewable energy, recycling, and reusing waste, and using ecological materials; and the 'redesign' considers product design that is easy to repair and reuse.

[13]Table A1 and Table A2 in the Appendix present the main statistical summary.

TABLE 2 Factor loadings and unique variances.

Variable	Factor 1 Knowledge spillovers	Factor 2 Environmental spillovers	Uniqueness
Eco-innovation inputs	0.711	0.182	0.462
Eco-innovation outputs	0.796	0.138	0.347
Eco-innovation activities	0.507	0.179	0.711
Resource efficiency outcomes	0.168	0.664	0.531
Socio-economic outcomes	0.175	0.231	0.516

Source: own elaboration from the EcoInnovation Scoreboard.

of the markets where the firm operates, as well as its age, size and sector.

The information collected during the period 2015–2021 shows that European SMEs are highly committed to actions related to CE. For instance, in 2015, only 12.15% of firms did not conduct any substantive action to become more resource-efficient, while in 2021, the inactive firms had further dropped to 7.35%. In 2015, 51.98% of European SMEs conducted between one and four actions, while 35.87% undertook more measures. Additionally, in 2021, 50.49% of the firms undertook between one and four actions and the remaining 42.16% engaged in more than four actions. In summary, 87.35% of SMEs took at least one of the CE actions in 2015, while in 2021 the active firms in the CE transition accounted for 92.65%. These results show that CE actions are persistent over time so that SMEs involved make profitable the initial physical investments and the experiences accumulated in the CE management.

4 | METHODOLOGY

This section details the econometric treatment of the dataset. First, explaining the aggregation of the external factors in two groups. Second, developing the modelling of CE activities, as well as defining the test to analyse significant variations in the determinants across subsamples.

4.1 | Factor indicators

We carefully address the introduction of the indicators from the Eco-Innovation Scoreboard into the modelling, because of a lack of interpretability of certain indicators and strong correlations between different aggregations. To circumvent this, we apply common factor models using the principal-factor method. This methodology finds F factors from K variables, reconstructing the original variables linearly:

$$\theta_{i,j} = \sum_{f=1}^{F} z_{i,f} b_{f,j} + e_{i,j} \quad (1)$$

where $\theta_{i,j}$ *is the value of the observation i on the variable j;* $z_{i,f}$ *is the observation i of the common factor f;* $b_{f,j}$ *are the linear coefficients, referred to as factor loadings;* $e_{i,j}$ *is the residual, referred to as unique variance. The reconstructed variable and factor loadings are predicted from the original correlation matrix, by minimising the residual (unique) variance across all variables.*

After orthogonal rotation, we obtain the following factor loadings and unique variances (Table 2):

After estimation, the factors obtained and their components (factor loadings) must be interpreted subjectively, analysing, and interpreting the weight of each variable on each factor. By previous consensus (Guadagnoli & Velicer, 1988), factor loadings higher than 0.4 are sufficient to be considered stable, thus determining a strong correlation between a determined variable and a factor.

Consequently, we differentiate two combinations. From the indicators belonging to Eurostat and the Eco-Innovation Scoreboard, we obtain two groups of interest. On the one hand, Factor 1 captures the existing knowledge spillovers, where aggregate public and private investments (in terms of R&D, financial resources and human capital) converge with aggregate eco-innovation outcomes in the form of patents and publications and the aggregate implementation of sustainable activities in SMEs. On the other hand, Factor 2 is composed of two proxies of the aggregate productivity increases because of the implementation of resource efficiency actions and the aggregate exports, labour and value added driven by green products. We interpret this factor as the environmental spillovers from the economic environment of a particular firm.[14]

We interpret knowledge and environmental spillovers as indirect effects driven by public and private actors that improve pro-environmental awareness and increase the likelihood of engaging in eco-innovation activities. Knowledge spillovers capture the aggregated effort, in terms of innovation inputs and outputs, to build a more CE. Environmental spillovers captured in Factor 2 integrate the efficiency gains from a better management of water, energy and materials, as well as the weight of eco-industries in terms of value-added, employment and exports. Indirectly, the evolution of consumer's preferences towards more sustainable products and services is also captured in this dimension.

[14]It is necessary to mention that the values of the scores of the two factors cannot be interpreted directly, but their introduction into the modelling allows us to identify the sign of their impact, whether positive or negative.

TABLE 3 Multivariate probit outcomes.

	Reduce					Recycle					Redesign				
Variable	2015	2018	2021	Test 15–18	Test 15–21	2015	2018	2021	Test 15–18	Test 15–21	2015	2018	2021	Test 15–18	Test 15–21
Knowledge spillovers	0.119* (0.071)	0.134*** (0.047)	0.016 (0.073)	0.185	−1.008	0.188*** (0.060)	0.144** (0.058)	0.175*** (0.065)	−0.517	−0.142	0.201*** (0.056)	0.129*** (0.031)	0.131** (0.053)	−1.11	−0.896
Environmental spillovers	−0.010 (0.078)	0.155** (0.066)	0.186*** (0.058)	1.616	2.022**	−0.087 (0.094)	0.109** (0.055)	0.080** (0.038)	1.797*	1.644*	−0.038 (0.063)	0.068 (0.050)	0.04 (0.037)	1.305	1.06
Internal factors															
Own financial resources	0.298*** (0.055)	0.178*** (0.050)	0.367*** (0.044)	−1.613	0.970	0.123*** (0.040)	0.061* (0.036)	0.212*** (0.035)	−1.149	1.697*	0.033 (0.051)	0.063* (0.037)	0.158*** (0.043)	0.49	1.878*
Own technical expertise	0.286*** (0.052)	0.141** (0.062)	0.308*** (0.042)	−1.801*	0.326	0.084** (0.035)	0.180*** (0.037)	0.156*** (0.031)	1.900*	1.555	0.282*** (0.035)	0.279*** (0.040)	0.280*** (0.041)	−0.058	−0.035
Between 1 and 5% of annual revenue	0.233*** (0.069)	0.166** (0.067)	0.218*** (0.074)	−0.690	−0.149	0.213*** (0.034)	0.257*** (0.044)	0.239*** (0.043)	0.809	0.483	0.314*** (0.039)	0.313*** (0.038)	0.283*** (0.040)	−0.026	−0.558
More than 5%	0.092 (0.087)	−0.017 (0.093)	0.155 (0.098)	−0.858	0.482	0.253*** (0.054)	0.286*** (0.057)	0.252*** (0.081)	0.415	−0.012	0.495*** (0.055)	0.587*** (0.052)	0.452*** (0.058)	1.22	−0.539
External factors															
Public funding	−0.062 (0.128)	0.221* (0.116)	0.175** (0.088)	1.638	1.528	0.138 (0.092)	0.083 (0.073)	0.146*** (0.047)	−0.472	0.074	0.044 (0.066)	0.139** (0.061)	0.075 (0.061)	1.064	0.356
Assistance from public entities	0.314** (0.138)	0.215* (0.126)	0.260** (0.102)	−0.529	−0.317	0.136* (0.082)	0.142 (0.087)	0.021 (0.058)	0.053	−1.155	0.132 (0.093)	−0.061 (0.066)	0.112* (0.059)	−1.685*	−0.182
Private funding	0.076 (0.094)	0.027 (0.093)	−0.034 (0.108)	−0.372	−0.769	−0.035 (0.052)	0.151*** (0.056)	0.098 (0.061)	2.433**	1.665*	0.077 (0.081)	0.016 (0.050)	0.042 (0.054)	−0.646	−0.365
Assistance from private entities	0.217*** (0.064)	0.181** (0.076)	0.253*** (0.060)	−0.358	0.414	0.131*** (0.045)	0.065 (0.044)	0.124** (0.057)	−1.050	−0.104	−0.051 (0.051)	0.125** (0.049)	0.052 (0.053)	2.495**	1.413
Barriers to adopt CE															
Administrative and legal barriers	0.086** (0.040)	0.170*** (0.053)	0.187*** (0.043)	1.284	1.738*	0.109*** (0.036)	0.048 (0.044)	0.108*** (0.030)	−1.080	−0.019	0.183*** (0.028)	0.089*** (0.034)	0.108*** (0.026)	−2.129**	−1.982**
Cost barriers	0.197*** (0.050)	0.209*** (0.071)	0.297*** (0.058)	0.138	1.321	0.126*** (0.037)	0.181*** (0.042)	0.178*** (0.040)	0.996	0.952	0.096** (0.041)	0.079** (0.037)	0.171*** (0.035)	−0.305	1.405
Experience barriers	0.262*** (0.049)	0.218*** (0.060)	0.130*** (0.047)	−0.571	−1.932*	0.070* (0.038)	0.074*** (0.029)	0.144*** (0.042)	0.086	1.303	0.132*** (0.047)	0.137*** (0.036)	0.249*** (0.033)	0.081	2.037**

TABLE 3 (Continued)

Variable	Reduce 2015	Reduce 2018	Reduce 2021	Reduce Test 15–18	Reduce Test 15–21	Recycle 2015	Recycle 2018	Recycle 2021	Recycle Test 15–18	Recycle Test 15–21	Redesign 2015	Redesign 2018	Redesign 2021	Redesign Test 15–18	Redesign Test 15–21
Control variables															
Selling to the national market	0.087 (0.077)	0.127 (0.085)	0.189*** (0.059)	0.349	1.051	0.184*** (0.037)	0.316*** (0.035)	0.175*** (0.039)	2.606***	−0.177	0.158*** (0.041)	0.058 (0.036)	0.187*** (0.037)	−1.827*	0.527
Selling abroad	0.167 (0.102)	0.037 (0.098)	−0.052 (0.047)	−0.913	−1.948*	0.234*** (0.064)	0.426*** (0.052)	0.225*** (0.042)	2.328**	−0.119	0.487*** (0.068)	0.324*** (0.068)	0.423*** (0.060)	−1.696*	−0.703
Age (logs)	0.046* (0.027)	0.067** (0.034)	0.018 (0.034)	0.485	−0.666	0.010 (0.024)	0.078*** (0.015)	0.083*** (0.019)	2.376**	2.400**	−0.025* (0.013)	−0.01 (0.020)	−0.057*** (0.016)	0.639	−1.562
Size (logs)	0.013 (0.019)	0.0124 (0.013)	−0.005 (0.015)	−0.016	−0.733	0.104*** (0.016)	0.089*** (0.012)	0.053*** (0.013)	−0.723	−2.455**	0.018 (0.013)	−0.001 (0.011)	−0.024*** (0.009)	−1.12	−2.621**
Observations	8,175	8,363	9,823			8,175	8,363	9,823			8,175	8,363	9,823		

Notes: Robust standard errors in parentheses. Log pseudo-likelihood (2015): −11,206.28. Log pseudo-likelihood (2018): −11,470.79. Log pseudo-likelihood (2021): −13,581.30.
$^{***}p < .01$, $^{**}p < .05$, and $^{*}p < .1$.

4.2 | Modelling structure and test of heterogenous coefficients

Our econometric structure assumes the existence of interdependencies in the adoption of CE practices. In other words, the adoption of a particular CE action might limit the adoption of others because of a lack of resources and capabilities or, vice versa, foster the adoption of other actions, as it might provide new knowledge and increase the capabilities of undertaking other actions. We conducted several correlation tests, which provide solid evidence for the existence of a significant pairwise correlation between equation errors.[15] Thus, independent binary probit models are not suitable for the estimation of CE activities. Considering that firms decide which CE actions to undertake simultaneously, our econometric model is a multivariate probit perspective, following the Geweke–Hajuvassilow–Keane method (Cappellari & Jenkins, 2003; Geweke, 1989; Hajivassiliou & McFadden, 1998; Keane, 1994).

Indexing the reduce, recycle and redesign by $m = 1,2,3$, respectively, we have the following multi-equation model:

$$y^*_{i,m} = \alpha_m + \beta_m X_{i,m} + \epsilon_{i,m} \quad (2)$$

Where:

$$y_{i,m} = \begin{cases} 1 \text{ if } y^*_{i,m} > 0 \\ 0 \text{ if } y^*_{i,m} < 0 \end{cases} \quad (3)$$

Note that $y_{i,m}$ represents the adoption of the activity m by firm i, α_m is the intercept of each equation, β_m is a vector of parameters multiplying the explanatory variables $X_{i,m}$, and $\epsilon_{i,m}$ are error terms with zero means, distributed as multivariate normal and correlated with the errors of the other equations, leading to a variance–covariance matrix V, which has values of 1 on the leading diagonal and correlations $\rho_{j,k} = \rho_{k,j}$ as the off-diagonal elements.

As the objective of this article is not limited to the determination of CE activities, we must develop a strategy to identify whether the drivers of CE practices change over time. For this reason, we run separated regressions for each one of the Eurobarometers FL426, FL456 and FL498, and test if the coefficients of a variable are statistically different across subsamples in the following manner:

$$Z = \frac{\tau_2 - \tau_1}{\sqrt{(\sigma_2^2 + \sigma_1^2)}}, Z \sim N_{0,1} \quad (4)$$

under the null hypothesis that the two parameters are equal. Here, τ_k represents the value of a determined coefficient and σ_k^2 its variance.

Always taking the wave 2015 as a reference, we apply this test twice: the first to observe the change during the period 2015–2018 and the second for the period 2015–2021 (which is of special relevance because of the arrival of COVID-19).

[15]We present these correlations in Section 5.

We should note that firm age and size have been converted to logarithms to improve the normality of the data. Also, we introduce sector fixed effects to capture structural differences between sector clusters. Finally, to control for firm homogeneity, the error terms are clustered by country; this increases the robustness of the within-country approach.

5 | RESULTS

The following section presents our results concerning the drivers of each of the three major CE actions. The regression outcomes are presented in three different groups, in which the first three columns show the results for each of the three waves, while the next two columns show the tests that indicate if the changes registered in 2018 and 2021 vary concerning the values of 2015. They are also differentiated depending on whether the firms perform reduce, recycle or redesign actions.

Table 3 shows the impacts of the drivers that facilitate the adoption of CE actions. In general, the multivariate probit results highlight that public policy drivers related to the promotion of science and the development of eco-innovations are positively associated with the probability of adopting CE actions. They also manifest the relevance of the productive ecosystem where the firm operates in enhancing CE initiatives among SMEs. More specifically, it demonstrates the significant and positive influence of our proxy of knowledge spillovers on the likelihood of developing 'reduce' activities in 2015 and 2018; this effect, however, does not hold in 2021. Our variable representing the effects of the socio-economic framework is positively associated with this type of activity in 2018 and 2021, increasing its impact and relevance in the last period.

Among the internal forces, it is worth highlighting the positive effects of a firm's internal resources in being available to finance actions aimed at reducing water, energy and natural material usage. The results show that European SMEs require lower investment to implement reducing actions because a reduction in the use of materials, water and energy is more related to management changes and organisational expertise rather than the incorporation of new technologies, resulting in a moderate financial effort. In addition, internal technical skills and experience play a particularly important role, but the effects diminish in the period 2015–2018.

Regarding the influence of external financial resources, their effect is moderate. While access to advice and assistance, public and private, plays a relevant role while the rest of dimensions do not. The role of public funding is greater during the last two waves, while private financing does not have significant impacts. Interestingly, selling to the national market becomes a determinant in 2021, a context subject to the lockdown and mobility measures applied by the European governments during the first period of the COVID-19 pandemic. Concerning the obstacles, we find increasingly relevant barriers in legal and administrative efforts, while the lack of training and personal experience plays a more moderate role as the years go by. Other characteristics such as firm age and size play an ambiguous but moderate role.

Let us continue with the determinants of recycling activities. The existence of knowledge spillovers is, in this case, positively associated with these actions in all subsamples, without showing any substantial change. This shows that the public and private effort towards the development of eco-innovations has consistently driven recycling activities among SMEs. The role of operating in a socio-economic framework devoted to the sustainable transition has a positive and growing role in 2015 and 2021, which manifests a fundamental idea. In a context where the adoption of CE practices is not sufficiently widespread, the gains from these activities are relatively unnoticed. Thus, firms would be less likely to undertake sustainable strategies, as they would be associated with higher uncertainty. However, if the adoption of CE practices is sufficiently widespread that resource efficiencies and productivity gains can be more easily identified, providing incentives to undertake these actions. Additionally, the pool of knowledge related to sustainable actions in this economy would be larger, which facilitates the adoption of CE actions.

If we compare the three years, both a firm's own financial resources and technical expertise have an increasing effect on the likelihood of implementing recycling activities. In this case, firms need to devote a greater financial effort as compared with reducing activities, because of the increasing complexity of these actions. Public funding seems to gain weight in the period 2021, while private funding has a significant impact only in 2015. For its part, public assistance and advice lose their leading role, while assistance from private firms is a key driver of recycling actions.

Trading beyond a local market scope seems to provide incentives to adopt recycling activities, the effect of these variables increases during the period 2015–2018 but moderates again in 2021. Considering the obstacles to the adoption of CE measures, we observe that all of them are relevant and significant. Contrary to the 'reduce' actions, firm age and size become key explanatory variables, the first presenting clear growth, and the second reducing its effects in 2021.

Finally, for redesign activities, knowledge spillovers are again relevant and play a positive influence in the likelihood of developing these activities. However, in this case, we do not observe complementarities driven by the environmental spillovers. Redesign activities are the most complex of the three CE activities. They are most closely related to product innovation, and address market needs directly. Therefore, redesign is the most knowledge intensive activity, requiring relatively larger R&D investment, market studies and product development.

Taking this into account, it is natural to expect a positive impact of public and private investment directed at the generation of new knowledge. What is surprising is that firms do not need to identify the gains from the rest of the economy to undertake redesign activities. From a self-selection approach to innovation, those firms undertaking redesign activities, might already be the most productive and successful ones. Consequently, they have already identified the gains from these activities and do not need signals from the rest of the economy.

Regarding the internal factors, the effect of the internal financial resources emerges in 2015 and grows during the period 2018–2021 and, like recycling activities, the amount of investment devoted to redesign is greater than that for reducing activities. A firm's own

TABLE 4 Correlations between multivariate probit equations.

	2015	2018	2022
Reduce-recycle	−0.219*** (0.039)	−0.249*** (0.038)	−0.127*** (0.031)
Reduce-redesign	−0.020 (0.032)	−0.012 (0.030)	0.054** (0.022)
Recycle-redesign	0.145*** (0.018)	0.120*** (0.020)	0.153*** (0.021)

Note: Coefficients and Standard errors (between brackets) reported.
*p < .10, **p < .05, and ***p < .01.

technical expertise is fundamental to redesign products to be more sustainable. Concerning the external forces, they do not present a high level of significance, except for public funding and assistance in 2018 and 2021 respectively, and private assistance in 2018.

Administrative and legal barriers become less relevant with time, but barriers related with a lack of expertise become more prominent. The effect of cost barriers remains positive and relatively constant. Selling beyond a local market scope provides incentives to develop more sustainable products, but its effects reduce during the lapse 2015–2018. Contrary to the rest of specifications, in this case, young and smaller firms are more prone to develop this CE activity, especially in 2021.

We can extract several common facts in all regression outcomes. On the one hand, knowledge spillovers capture the aggregate public and private financial effort to develop research focused on sustainable outcomes, as well as eco-innovation outcomes and activities. Their effect on the likelihood of developing all the CE practices enumerated is positive and consistent across the three different subsamples, demonstrating the fundamental role that fostering the generation of knowledge has on the adoption of these strategies.

On the other hand, the environmental spillovers capture aggregated productivity gains from sustainable actions, green exports, value added and personnel working in these activities. Overall, environmental spillovers have gained increasing relevance during the period 2018–2021, in which the adoption of CE becomes more relatively widespread. As aforementioned, these externalities provide a key signal to firms, indicating that the investment in sustainability and the adoption of CE practices has the potential to generate resource efficiency gains, increase productivity, and improve a firm's market position.

Assuming these two factors as proxy capturing a multitude of spillovers from public policies, we demonstrate that they have a positive and effective impact on CE actions, answering RQ1 positively. However, while the environmental spillovers have a growing impact, knowledge spillovers do not. Hence, we obtain a partial positive answer to RQ2. Additionally, it is worth noting that a firm's internal effort is fundamental, and on a lesser scale, receiving public and private investment and advice.

Table 4 shows the correlations between the three CE activities. On the one hand, it shows that firms developing reduce activities are less prone to recycle and more likely to redesign in 2022. As reducing actions are the less technological intensive actions, we assume that their adoption is more common among firms with lower knowledge capital and less able to undertake the rest of activities, which are more knowledge intensive. On the other hand, those firms recycling are always more likely to adopt redesign strategies.

Complementing this with the previous idea, recycle activities present an intermediate level of knowledge intensiveness. They require constituent a more complex organisational changes and innovations, directed to a change in organisational culture to implement a more sustainable approach. Consequently, reduce presents complementarities with the likelihood of redesign existing product lines to improve their sustainability and approach better market demands. All these ideas provide an answer to RQ3, demonstrating a growing correlation between reduce and redesign activities, the rest remaining constant.

6 | CONCLUSIONS AND POLICY IMPLICATIONS

The Circular Economy Action Plan defined by the European Commission aims to support measures to mitigate the consequences of climate change among a multitude of agents from governments, universities, technology centres and, of course, European firms. SMEs face challenges, but they also have new opportunities related to the development of a Green economy. To achieve a certain efficient implementation of policy measures, we need to evaluate the direct measures affecting the adoption of CE measures by SMEs, and the indirect effects of public policies through the promotion of knowledge spillovers and the generation of a new institutional framework. This research provides empirical evidence on the impact of these public policies on European SMEs during the period 2015–2021.

In line with previous evidence, our results confirm that SMEs perceive the complexity of the regulatory environment and the lack of public funding from governments as important barriers (Ghisetti & Montresor, 2020; Mura et al., 2020), as firms adopting CE actions identify the challenges related to costs, experience and legislation. However, our results show that knowledge spillovers and the institutional and socio-economic framework influence the adoption of CE measures significantly. They also have a heterogenous effect on the CE actions throughout the period 2015–2021. Like Zhu et al. (2022), these temporary dynamics capture the presence of 'temporary learning' because of the accumulative learning capabilities of SMEs.

First, knowledge spillovers are fundamental for all the three CE activities identified in this research. Despite their effect remaining statistically constant during our period of analysis, they manifest the key role of public and private investment directed towards the generation of knowledge to increase the sustainable behaviour of European

SMEs. Second, we prove that the adoption of CE activities must be a common approach to be increasingly successful. According to the growing effect of the environmental spillovers, when few firms adopt reduce or recycle activities, the resources efficiency and productivity gains are not sufficient, or clear enough, to attract other firms towards increasing their sustainable behaviour. While when the adoption of CE actions is relatively widespread, this expertise spreads better on the socio-economic context, providing incentives to non-sustainable firms to introduce a CE approach to not lag behind. Our results highlight that the drivers that promote the adoption of CE actions are bidirectional. Public policies adopt a top-down approach that is complemented by down-up spillovers related to the environmental awareness of other firms.

Additionally, our results highlight the existence of 'experience learning' between recycling and redesign activities, which emerges because of the presence of complementarities between both CE strategies. Conversely, the strategy of reducing has a negative interrelationship with the other CE measures. These interrelationships appear to be quite persistent over time. However, during the last period of observation, there is a change in the strategy of the firms since the action of reduce is complementary to the redesign strategy. While previous (Garcés-Ayerbe et al., 2019; Katz-Gerro & Lopez Sintas, 2019) show a gradual implementation of CE practices by firms, our results confirm that there can be a certain learning in the adoption of CE practices in comparison with others.

Despite the relevant empirical results obtained by adopting a temporal perspective in our study, we must also consider some limitations in our research. First, in terms of the interdependences among CE strategies, it would be desirable to have access to panel data to estimate the change in learning between periods. Currently, we can analyse the experience learning during the period of observation, but not a specific firm's previous experience, nor the recent policy developments from 2021 to 2023. Such an approach would enrich the analysis, but our perspective is sufficient to identify key tendencies. Second, our database does not give information on the investment effort or the radicalness of the eco-innovation. Consequently, we homogeneously treat radical and incremental eco-innovations. More detailed information would allow insight into the scope of the practices adopted by SMEs and would indicate the speed of the transition to a more CE in Europe.

Our results show important implications for policymakers and managers. On the one hand, if policymakers intend to promote the transition to a more sustainable and efficient economy in Europe, public policies must involve diverse actors. We show that the implementation of CE actions among European SMEs has increased because of changes in the institutional framework. Hence, to transit towards a CE, policymakers should channel incentives, not only to the development of CEIs, but to the entire innovation system. This includes governments, universities, public research centres, business organisations, territorial institutions and, of course, European firms. Those interventions affecting the institutional framework affect those firms operating in a particular country and incentivise the adoption of CE practices. European SMEs prove to be very sensitive to these institutional drivers in addition to other internal and external drivers. Additionally, to increase the impact of environmental externalities, public institutions should facilitate knowledge transfer between different segments of the innovation system. The consideration of knowledge spillovers by policy designers is critical for achieving a CE, which suggests a simultaneous approach that operates from the top down through public institutions and upwards from industry. This simultaneous top-down and bottom-up approach requires that the measures of government bodies and policymakers attempt to make firms collectively aware of both environmental issues and the social benefit of industrial activities (de Melo et al., 2022).

From the point of view of the implications for managers, our results raised the attention to the importance of the institutional framework with which they are in contact and collaborate is crucial to adopt new CE practices. Institutional forces may facilitate the adoption thanks to the existing spillovers and incentives that exist in the economy. Collaboration with third parties to have access to flows of knowledge relevant to the development of CEIs. This is a strategic issue to maintain the competitive advantage with respect to their competitors and to diminish the uncertainty of adopting new practices.

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CONFLICT OF INTEREST STATEMENT

The authors report there are no competing interests to declare.

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APPENDIX A

TABLE A1 Summary statistics. Mean and standard deviation between brackets.

Dependent variables	2015	2018	2021	Total
Reduce	0.808 (0.394)	0.818 (0.386)	0.843 (0.364)	0.824 (0.381)
Recycle	0.576 (0.494)	0.602 (0.490)	0.666 (0.472)	0.619 (0.486)
Redesign	0.229 (0.420)	0.255 (0.436)	0.272 (0.445)	0.253 (0.435)
Indices				
Government's green R&D appropriations and outlays	0.027 (0.022)	0.030 (0.023)	0.028 (0.020)	0.028 (0.022)
Government's R&D investment per capita	3.317 (3.274)	3.494 (3.382)	4.474 (3.872)	3.795 (3.574)
Total R&D personnel and researchers	1.396 (0.506)	1.243 (0.518)	1.266 (0.519)	1.306 (0.519)
Total value of green early-stage investments	57.951 (86.219)	114.184(305.878)	85.494(239.34)	84.584(226.253)
Eco-innovation related patents	27.325 (29.896)	35.043 (37.565)	30.455(30.731)	30.774 (32.934)
Eco-innovation related publications	16.143 (9.281)	11.782 (7.822)	15.254(10.197)	14.473 (9.347)
Implementation of resource efficiency actions among SMEs	1.659 (0.409)	1.819 (0.393)	1.685 (0.350)	1.712 (0.392)
Implementation of sustainable products among SMEs	0.218 (0.094)	0.220 (0.100)	0.220 (0.100)	0.219 (0.098)
Firm characteristics				
Own financial resources	0.602 (0.490)	0.617 (0.486)	0.656 (0.475)	0.626 (0.484)
Own technical resources	0.519 (0.500)	0.540 (0.498)	0.527 (0.499)	0.529 (0.499)
No investment in CE activities	0.220 (0.414)	0.232 (0.422)	0.206 (0.405)	0.219 (0.413)
Investing less than 5% of the annual revenue	0.665 (0.472)	0.649 (0.477)	0.632 (0.482)	0.648 (0.478)
Investing more than 5% of the annual revenue	0.115 (0.319)	0.119 (0.323)	0.161 (0.368)	0.133 (0.340)
Public investment	0.054 (0.226)	0.074 (0.262)	0.106 (0.308)	0.079 (0.270)
Public assistance	0.044 (0.205)	0.058 (0.233)	0.065 (0.247)	0.056 (0.230)
Private investment	0.060 (0.238)	0.080 (0.271)	0.082 (0.274)	0.074 (0.262)
Private assistance	0.137 (0.343)	0.163 (0.370)	0.180 (0.384)	0.161 (0.367)
Selling in the national market	0.193 (0.395)	0.197 (0.397)	0.200 (0.400)	0.197 (0.398)
Selling in international markets	0.086 (0.281)	0.094 (0.292)	0.133 (0.340)	0.106 (0.307)
Identifying legal barriers	0.355 (0.479)	0.405 (0.491)	0.426 (0.495)	0.397 (0.489)
Identifying cost barriers	0.235 (0.424)	0.263 (0.440)	0.282 (0.450)	0.262 (0.439)
Identifying experience barriers	0.218 (0.413)	0.234 (0.423)	0.353 (0.478)	0.272 (0.445)
Firm age	25.325 (22.179)	26.701 (24.793)	26.715(25.033)	26.269 (24.092)
Firm size	131.084 (1,017.60)	116.153 (1,034.97)	94.831 (944.42)	113.118 (997.13)
Observations	**8,175**	**8,363**	**9,823**	**26,361**

Source: own elaboration.

TABLE A2 Correlation matrix.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Reduce	1									
(2) Recycle	0.291	1								
(3) Redesign	0.188	0.217	1							
(4) Public policy drivers	0.046	0.086	0.058	1						
(5) System drivers	0.159	0.179	0.125	0.091	1					
(6) Own financial resources	0.391	0.246	0.120	−0.036	0.043	1				
(7) Own technical resources	0.330	0.219	0.180	0.043	0.077	0.089	1			
(8) No investment in CE activities	−0.089	−0.142	−0.126	−0.024	−0.028	−0.083	−0.020	1		
(9) Investing less than 5% of the annual revenue	0.078	0.094	0.049	0.026	0.039	0.048	0.004	−0.718	1	
(10) Investing more than 5% of the annual revenue	−0.001	0.042	0.084	−0.008	−0.020	0.031	0.018	−0.208	−0.532	1
(11) Public investment	0.103	0.116	0.080	0.033	0.042	0.027	0.028	−0.092	0.028	0.072
(12) Public assistance	0.095	0.098	0.072	0.091	0.058	0.026	0.034	−0.062	0.032	0.030
(13) Private investment	0.092	0.097	0.069	0.004	0.052	0.015	0.031	−0.083	0.014	0.080
(14) Private assistance	0.156	0.165	0.100	0.129	0.104	0.001	0.036	−0.136	0.091	0.038
(15) Selling in the national market	0.084	0.095	0.062	0.091	0.051	0.058	0.056	−0.056	0.026	0.032
(16) Selling in international markets	0.062	0.101	0.120	0.031	0.042	0.046	0.074	−0.084	0.026	0.066
(17) Identifying legal barriers	0.273	0.211	0.157	−0.050	0.077	0.191	0.165	−0.149	0.078	0.070
(18) Identifying cost barriers	0.082	0.106	0.105	0.029	0.067	0.046	0.040	−0.122	0.082	0.034
(19) Identifying experience barriers	0.212	0.174	0.148	0.024	0.065	0.144	0.113	−0.095	0.061	0.030
(20) Firm age	0.102	0.129	0.041	0.139	0.149	0.060	0.057	−0.085	0.082	−0.012
(21) Firm size	0.137	0.193	0.074	0.027	0.054	0.100	0.098	−0.216	0.165	0.030

Source: own elaboration.

TABLE A2 (Continued)

	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
(1) Reduce											
(2) Recycle											
(3) Redesign											
(4) Public policy drivers											
(5) System drivers											
(6) Own financial resources											
(7) Own technical resources											
(8) No investment in CE activities											
(9) Investing less than 5% of the annual revenue											

TABLE A2 (Continued)

	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
(10) Investing more than 5% of the annual revenue											
(11) Public investment	1										
(12) Public assistance	0.366	1									
(13) Private investment	0.337	0.220	1								
(14) Private assistance	0.365	0.386	0.324	1							
(15) Selling in the national market	0.027	0.030	0.029	0.051	1						
(16) Selling in international markets	0.054	0.037	0.046	0.063	−0.171	1					
(17) Identifying legal barriers	0.128	0.107	0.110	0.132	0.063	0.059	1				
(18) Identifying cost barriers	0.089	0.088	0.073	0.102	0.045	0.039	0.324	1			
(19) Identifying experience barriers	0.093	0.101	0.081	0.117	0.049	0.028	0.332	0.270	1		
(20) Firm age	0.080	0.063	0.038	0.114	0.010	0.061	0.073	0.062	0.023	1	
(21) Firm size	0.131	0.099	0.074	0.187	−0.027	0.135	0.108	0.079	0.038	0.324	1

Source: own elaboration.