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# Government support, co-creation, and digital transformation on the road to sustainable innovation

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ABSTRACT

This study examines whether and how different types of government support (financial, technological, market) impact the three types of co-creation efforts (product, process, and knowledge co-creation) of SMEs and how these, in turn, impact sustainable innovation outcomes. It also investigates whether digital transformation mediates the positive relationship between the three types of co-creation and sustainable innovation. The conceptual model is tested on an original dataset of 188 SMEs in France, collected in 2025. Findings indicate that product co-creation is positively affected by government technological support, and knowledge co-creation by market support. The mediation effect of digital transformation is confirmed for the relationship between product co-creation and sustainable innovation, while process and knowledge co-creation directly lead to sustainable innovation. The implications of the study for research, policy and practice are discussed.

## 1. Introduction

Sustainable innovation – innovation that improves sustainability performance and outcomes in the ecological, economic and social domains (Boons et al., 2013) – has become a priority for firms facing increasing environmental and social challenges. Sustainable innovation aims at producing sustainability outcomes through processes that do not harm people and the planet, through innovations that do good by offering solutions that foster sustainable development, and through governance schemes that facilitate such innovations (Voegetlin and Scherer, 2017). Sustainable innovation differs from conventional innovation because it often requires systemic transformations that extend beyond the boundaries of individual firms and involve multiple actors across innovation ecosystems (Oksanen and Hautamäki, 2015; McGahan et al., 2021). To achieve sustainability outcomes, whether environmental, social, or economic, firms must mobilise a broad range of knowledge and competences that are rarely available within a single organisation (Ramaswamy and Ozcan, 2014; Cillo et al., 2019; von Wirth et al., 2019; Araújo and Franco, 2021; Chauhan et al., 2022). The use of co-creation – a collaboration process in which organisations jointly generate new knowledge, new products or new processes (De Silva and Rossi, 2018) – is therefore fundamental to gather complementary resources, coordinate the different efforts, align heterogeneous perspectives, build legitimacy around solutions, and generate forms of value that go beyond traditional innovation performance (Voorberg et al., 2015; De Silva et al., 2020, 2021a; Stojčić et al., 2024).

However, firms, especially smaller ones, often encounter significant difficulties in collaborating with external organisations. Literature has widely documented the existence of a variety of barriers to small firms' engagement in collaborative innovation (Bigliardi and Galati, 2016). Limited human and financial resources, a scarcity of appropriate skills, and organisational and cognitive barriers can hinder their ability to collaborate with external partners (Bruneel et al., 2010; Radziwon and Bogers, 2019; Arranz et al., 2020). As a result, developing sustainability-oriented innovations independently can become particularly challenging for these firms. At the same time, these very limitations may encourage small and medium-sized firms (SMEs) that are willing to, or need to, engage in sustainable innovations to seek out co-creation processes to access complementary competences, infrastructures, and legitimacy resources available within the broader innovation ecosystem (De Silva et al., 2021b).

Public support can play an important role in stimulating co-creation. Governments increasingly intervene not only through direct financial

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support, but also by shaping the institutional, technological, and relational conditions that enable collaboration among ecosystem actors (Edler and Fagerberg, 2017; McGahan et al., 2021). Through subsidies, technological infrastructures, networking platforms, regulatory guidance, and market-shaping interventions, public actors can reduce coordination costs, facilitate knowledge exchange, and support the emergence of collaborative ecosystems oriented toward sustainability transitions (Markard et al., 2012; Borrás and Edquist, 2013; Oksanen and Hautamäki, 2015). Rather than acting solely as providers of financial incentives, public actors may therefore operate as ecosystem orchestrators that enable firms and other stakeholders to engage in co-creation processes aimed at generating sustainable innovation (Aarikka-Stenroos and Ritala, 2017; Edler and Fagerberg, 2017; McGahan et al., 2021). Research has shown how public policies support open innovation of firms in European countries, with less innovative firms benefiting the most from public incentives (Cano-Kollmann et al., 2017).

Importantly, however, co-creation for sustainable innovation is not a homogeneous phenomenon. Firms may engage in product co-creation to develop sustainable offerings, in process co-creation to redesign routines from an environmental-efficiency perspective, or in knowledge co-creation to generate new insights for socio-technical change (De Silva and Rossi, 2018; Cillo et al., 2019). These forms of co-creation differ in their resource requirements, cognitive demands, and coordination needs. At least in principle (given that no systematic evidence exists on this), it is plausible that different policy instruments are more or less effective at triggering different types of co-creation, depending on the specific barriers they address and the resources they mobilise (De Silva, 2025). In this research, we aim at uncovering the role of different types of public (government) support in stimulating product, process and knowledge co-creation.

At the same time, recent research highlights that the transition toward sustainable innovation depends not only on collaborative processes but also on firms' digital capabilities (Tabares et al., 2025). These capabilities enhance organisations' ability to coordinate efforts with external partners, integrate different data sources, experiment, and monitor environmental and social performance in real time (Nambisan et al., 2017; Tortora et al., 2021). As a consequence, digital capabilities may mediate the relationship between collaborative processes and sustainability outcomes. Firms that engage in co-creation but lack adequate digital infrastructure or digital capabilities may struggle to translate co-creation efforts into environmental or social innovation. Conversely, when such efforts are undertaken by digitally mature companies, they are better equipped to transform the results of co-creation processes into new sustainable knowledge, products or processes (Qureshi et al., 2021; Lu et al., 2023; Zhao and Qian, 2024).

This suggests that the influence of government support on sustainable innovation may operate through co-creation pathways, but is also shaped by the presence of different digital transformation capabilities. With this in mind, our goal is to address the following three interconnected questions: (i) *Does government* support *stimulate co-creation and if so, how?*; (ii) *Do different types of co-creation lead to sustainable innovation?* and (iii) *Does digital transformation mediate the relationship between co-creation and sustainable innovation?*

To address these questions, we develop a structural equation model that connects three types of government support (financial, technological, and market-oriented; Flanagan et al., 2011; Edler and Fagerberg, 2017) to three forms of co-creation (product, process, and knowledge; De Silva and Rossi, 2018), and examines how these collaborative pathways subsequently connect to sustainable innovation through the mediating role of digital transformation.

Our conceptual framework draws on the literature on co-creation, following, in particular, De Silva and Rossi (2018), who distinguish between product, process and knowledge co-creation. It also draws on the literature on sustainable innovation and sustainability in general, on the literature on the role of public support for innovation, and on the literature on digital transformation. Combining insights from these literature streams, we develop an original conceptual model. While different literature streams have analysed parts of the conceptual model that we have developed for the purpose of this research, there hasn't been any research integrating insights from these streams to advance knowledge on antecedents and consequences of co-creation, with a particular focus on sustainable innovation. We see this as a gap in the literature, which we aim to fill in this research. To test our conceptual model, we use an original dataset generated through a survey of 188 small and medium-sized enterprises (SMEs), operating in a variety of industries in France. Studying SMEs is particularly meaningful because these companies usually have fewer assets than larger companies and are thus in greater need of co-creating with external actors. Not having all the needed assets to develop new products, processes, or knowledge makes SMEs prone to looking for external complementary assets that they can combine with their own in the co-creation process. Moreover, SMEs often rely on government support to develop their activities (OECD, 2025).

The results show that technological support (e.g., support to adopt new technologies, free or low-cost technology audits) is positively associated with product co-creation, and market support (e.g., incentives for internationalisation, IPR protection, compliance with standards) with knowledge co-creation. Financial support (e.g. subsidies, grants, tax breaks) can be beneficial for knowledge co-creation when the financial companies are removed from the sample. By contrast, government support does not play a role in supporting process co-creation, although process co-creation itself leads to sustainable innovation.

The paper develops as follows. Section 2 presents the theoretical framework and develops the research hypotheses. The method section details the data used in the study as well as the empirical methods. Results and discussion sections follow. The last section concludes the paper, outlining its contributions to theory and practice, while also noting its limitations and directions for future research.

## 2. Theoretical framework

### 2.1. The co-creation of sustainable innovation

Co-creation refers to open innovation processes through which firms combine their resources with those of other actors in their ecosystem (other firms, universities, public institutions, etc.) to achieve goals that a single organisation would not be able to achieve alone (De Silva et al., 2021b, 2023). Through co-creation, resources and skills of different partners are not simply added to those of the others, but are augmented through cross-fertilisation processes. Hence, the benefits of co-creation go beyond the logic of accessing complementary assets to include the creation of completely new assets for the parties involved.

The academic literature has looked into firm-user and firm-firm co-creation for generating economic value for firms (Lakhani and Von Hippel, 2003; Dahlander and Piezunka, 2014; Giordino et al., 2025). Indeed, other firms and clients (users) can possess knowledge and skills to help the firm in its innovation endeavours, whether for designing products, improving processes or developing new knowledge that can be applied to a variety of purposes. Suppliers can also help the firm to innovate its products by contributing valuable assets such as information, ideas, or technical skills (Bettiga and Ciccullo, 2019). Beyond economic value, co-creation can be a way to generate sustainable innovation. Following Boons and Lüdeke-Freund (2013), sustainable innovation can be defined as an innovation process through which firms develop products, processes, or knowledge that reconcile economic performance with environmental protection and social value creation, by integrating sustainability considerations throughout the innovation lifecycle and across organisational boundaries (Stojčić et al., 2024).

Although co-creation for sustainable innovation is often treated as a unitary phenomenon, product, process, and knowledge co-creation differ substantially in their resource requirements, organisational

dynamics, and sustainability implications. These differences shape the conditions under which co-creation can emerge and contribute to sustainability transitions.

Product co-creation involves the joint development of new or improved offerings with external partners and typically requires shared technological infrastructures, complementary competences, and coordinated experimentation (De Silva and Rossi, 2018). Given that this kind of co-creation demands significant financial and technological resources, it may be particularly challenging for SMEs that are typically resource-constrained.

Process co-creation focuses on the joint redesign of organisational routines and operational practices (Damanpour and Aravind, 2006). It relies heavily on tacit knowledge, relational proximity, trust, and managerial capabilities to stabilise new routines across organisational boundaries (Baptista, 1999; Chaudhuri et al., 2023). Its sustainability effects mainly derive from changes in operational practices, such as waste reduction and improved resource efficiency.

Knowledge co-creation is more exploratory and open-ended, involving the joint production of shared understandings among heterogeneous actors, including firms, universities, and public institutions (De Silva et al., 2021b). Its outcomes are often indirect, operating through changes in cognitive frames, legitimacy, and institutional arrangements (von Wirth et al., 2019; Goyal et al., 2020). As a result, it depends strongly on shared interpretive frameworks and enabling institutional conditions.

Co-creation of new technologies or new and improved processes with universities and research labs – sometimes referred to as science-based co-creation (De Silva et al., 2021b) – has been considered as a phenomenon generating economic value (Etzkowitz et al., 2008; Levine and Prietula, 2014), but also social (Trencher et al., 2014) and environmental value. Co-creation with consultants such as KIBS (knowledge--intensive business services, see Consoli and Elche-Hortelano, 2010) can lead to benefits for the firm in economic, social and environmental dimensions. Consultants can help firms with different types of innovation (Amara et al., 2016); they are characterised by high knowledge intensity and can offer non-routine services to their clients (Doloreux and Shearmur, 2010). For instance, they can help develop products that cater to the needs of different population groups, optimise processes to reduce waste and carbon emissions, design and implement policies that foster diversity and inclusion, and undertake market studies to better understand local communities in which firms operate.

In addition to creating new or improved products and new processes, co-creation also helps to generate new knowledge, common visions and understandings that can bring about behavioural change or systemic reconfiguration, as well as build the social legitimacy necessary to support sustainability transitions (Aarikka-Stenroos and Ritala, 2017; von Wirth et al., 2019; Goyal et al., 2020; De Silva et al., 2021b). The transition to sustainable innovation requires companies to interact with the complexity and systemic interdependencies of innovation ecosystems (Adams et al., 2016). Furthermore, sustainable innovation is a dynamic and non-linear process involving different stakeholders with heterogeneous preferences. Collaboration with these actors is crucial for the company to fully understand its environmental and social impact, manage expectations, and acquire the relational capital and knowledge necessary for joint value creation (Werther and Chandler, 2011). Building on these insights, we expect co-creation of products, processes and knowledge to positively impact sustainable innovation, which we conceptualise as having three dimensions – economic, social and environmental –, in line with the academic literature (Boons et al., 2013).

### 2.2. Public support for the co-creation of sustainable innovation

Policymakers can target various barriers to co-creation and nurture distinct collaborative capabilities, either directly or through public innovation intermediaries (Edler and Fagerberg, 2017). Three main kinds of support can be distinguished: financial, technological and market support. These different types of government support, each targeting a specific category of barriers, are likely to have heterogeneous effects across the three forms of co-creation (product, process and knowledge co-creation), which, as we argued above, differ in their resource requirements, knowledge characteristics, and institutional conditions. We develop this argument in the three subsections below.

#### 2.2.1. Government financial support for co-creation

Policymakers can provide financial support to firms. Financial support reduces the risks and resource constraints that often inhibit firms from initiating sustainability-oriented collaborations. By providing grants, subsidies, or fiscal incentives, public actors create the slack resources required for experimentation and joint development, thereby lowering the perceived costs of failure and enabling firms to invest in the co-creation of knowledge, products, or processes (Borrás and Edquist, 2013).

The empirical literature on the impact of public financial incentives (such as subsidies and R&D tax breaks) on collaboration offers a picture that is generally, but not unanimously, positive. Meta-analyses such as those by Zúñiga-Vicente et al. (2014) and Dimos and Pugh (2016) suggest that financial incentives exert an additionality effect on collaboration. Public funds do not crowd out private spending, but act as a catalyst that pushes firms, especially SMEs, to engage in new collaborative activities that would otherwise be too costly or risky to undertake (Dimos and Pugh, 2016). However, some studies find that this positive effect depends on the characteristics of the policy instrument and on the broader collaborative environment. For example, some research finds that financial support is particularly effective when it explicitly targets programmes that favour network creation, or when it is sustained over time rather than provided only for a limited period of time (Lhuillery and Pfister, 2009; Jugend et al., 2018; Caloffi et al., 2018, 2019).

In the context of sustainable innovation, financial support may facilitate different forms of co-creation through different mechanisms. Product co-creation often requires substantial investments in prototyping, testing, experimentation, and joint product development activities, making financial resources particularly relevant for enabling collaborative product innovation. Process co-creation may also benefit from financial support, especially when firms need to experiment with new organisational routines, coordinate changes across partners, or implement new operational practices linked to sustainability objectives. In the case of knowledge co-creation, financial support may help create favourable conditions for interaction, collaborative learning, and participation in joint initiatives. However, the barriers affecting knowledge co-creation are often not only financial, but also cognitive and relational, since this form of collaboration requires actors to exchange tacit knowledge, align heterogeneous perspectives, and develop shared understandings (Bruneel et al., 2010; D'Este et al., 2012). Overall, prior literature suggests that financial incentives can reduce barriers to collaborative innovation and stimulate firms' engagement in co-creation activities, although the enabling mechanisms may vary across forms of co-creation. Despite these potential differences, existing literature has not looked into detail into the kinds of co-creation efforts targeted by such incentives (product-related, process-related or knowledge-related). We address this gap by investigating the impact of government financial support on different types of co-creation. We formulate our first set of hypotheses as follows:

**H1a.** Financial government support has a positive effect on product co-creation.

**H1b.** Financial government support has a positive effect on process co-creation.

**H1c.** Financial government support has a positive effect on knowledge co-creation.

#### 2.2.2. Government technological support for co-creation

The second kind of support policymakers can provide is technological. Technological support alleviates knowledge and capability gaps by enhancing absorptive capacity, facilitating access to scientific and technical expertise, and reducing cognitive distance across partners (Dolfsma and Seo, 2013). In the context of sustainable innovation, technological support may be particularly important because sustainability-oriented co-creation frequently requires firms to integrate heterogeneous forms of technical knowledge, experiment with new solutions, and coordinate activities across organisational boundaries. Often, this type of support is provided by public innovation intermediaries, who help firms to identify problems and opportunities for innovation, make sense of new technologies, and develop the capabilities needed to engage in collaborative innovation (Howells, 2006, 2024; Colovic et al., 2024). Innovation intermediaries can also provide access to laboratories where companies can collaborate to test new products or design new production processes (Colovic et al., 2025).

The enabling role of technological support, however, may differ across forms of co-creation. Technological support may facilitate product co-creation by enabling firms to integrate heterogeneous technical knowledge, reduce barriers to experimentation, and support collective problem-solving activities among ecosystem actors (Howells, 2006; Knockaert et al., 2014). Process co-creation may also benefit from technological support, particularly when firms seek to redesign operational routines, improve environmental efficiency, or implement digitally enabled organisational practices. However, process co-creation frequently depends not only on access to technological assets, but also on organisational and managerial capabilities related to change management, coordination, and the alignment of practices across partners (Damanpour and Aravind, 2006; Chaudhuri et al., 2023). In the case of knowledge co-creation, technological support may enable interaction and knowledge exchange by providing shared communication platforms, digital infrastructures, and collaborative tools. At the same time, knowledge co-creation often involves cognitive, relational, and institutional challenges associated with the integration of different interpretive frameworks, the development of mutual trust, and the creation of shared understandings among heterogeneous actors (von Wirth et al., 2019; De Silva et al., 2021b). Technological support may therefore contribute to facilitating knowledge co-creation, although technological resources alone may not be sufficient to overcome all barriers to collaborative knowledge generation. While government financial support and its effect have been the object of many studies, a much smaller number of studies have analysed the effects of technological incentives on collaboration, again finding generally positive effects (Knockaert et al., 2014; Caloffi et al., 2018). Limited research has systematically examined whether and how technological support affects product, process, and knowledge co-creation differently in the context of sustainable innovation. We address this gap by investigating the relationship between technological government support and different forms of co-creation. We therefore hypothesise:

**H2a**. Technological government support has a positive effect on product co-creation.

**H2b**. Technological government support has a positive effect on process co-creation.

**H2c**. Technological government support has a positive effect on knowledge co-creation.

#### 2.2.3. Government market support for co-creation

The third kind of support policymakers can provide is market support. This set of public interventions encompasses measures that aim to reduce market risks and costs associated with innovation, enabling firms to commercially exploit their innovations and enter new markets (Acs et al., 1997; Altomonte et al., 2013). This may occur by providing firms with support for internationalisation, direct assistance in overcoming bureaucratic obstacles or complying with new technical and regulatory standards (especially environmental and safety ones), support in protecting intellectual property (patents, trademarks) (Jaffe et al., 2002; Blind, 2016). Policymakers can also operate through public procurement, by creating stable demand expectations and reducing market uncertainty.

In the context of sustainable innovation, market-oriented support may play an important enabling role because sustainability transitions often depend not only on technological development but also on the creation of legitimacy, market acceptance, and shared expectations among ecosystem actors. By supporting market diversification, promoting standards, enabling certification or shaping market demand, public interventions strengthen firms' ability to engage in process co-creation aimed at reconfiguring routines, improving environmental efficiency or establishing collective practices (Lember et al., 2014; Goyal et al., 2020; Stojčić et al., 2024).

The enabling effects of market support, however, may differ across forms of co-creation. Product co-creation may benefit from market-oriented interventions when demand-side policies, public procurement schemes, or certification mechanisms stimulate co-design and early supplier involvement, thereby fostering joint development activities between firms and public actors (Uyarra and Flanagan, 2010; Georghiou et al., 2014). Process co-creation may also be facilitated by market support, particularly when firms are encouraged to adopt common environmental, safety, or quality standards that require coordination across supply chains and organisational boundaries, facilitate the emergence of shared routines, interoperable solutions and collective process improvements (Delmas and Montiel, 2009; Blind, 2016). However, the extent to which market support translates into process co-creation is likely to depend on firms' organisational capabilities and on the willingness of actors to coordinate changes in practices and routines.

Knowledge co-creation may be particularly facilitated by market-oriented support, because many market support instruments operate by creating shared expectations, reducing institutional uncertainty, and fostering interaction among heterogeneous actors. Incentives for participation in international trade fairs, networking initiatives, standard-setting activities, and public procurement schemes may stimulate exchanges among firms, universities, intermediaries, and other ecosystem actors, thereby supporting collaborative learning and the generation of shared understandings around sustainability challenges (Goyal et al., 2020; De Silva et al., 2021b). Evidence also indicates that market-related support, particularly when channelled through intermediaries, can reduce information asymmetries, lower transaction costs, and increase the legitimacy of collaborative initiatives, ultimately enabling joint problem solving and knowledge integration (Klerkx et al., 2009; Colovic et al., 2025). Drawing on this, we hypothesise:

**H3a**. Market government support has a positive effect on product co-creation.

**H3b**. Market government support has a positive effect on process co-creation.

**H3c**. Market government support has a positive effect on knowledge co-creation.

### 2.3. Co-creation of sustainable innovation: the mediating role of digital transformation

Co-creation with multiple actors within the firm's ecosystem has great potential to lead to sustainable innovation and generate economic, social and environmental benefits. A positive relationship between different types of co-creation and sustainable innovation can therefore be assumed to exist (Boons and Lüdeke-Freund, 2013). However, in the current era of the twin transition (digital and sustainability transition), some scholars argue that digital capabilities of firms are needed to enact

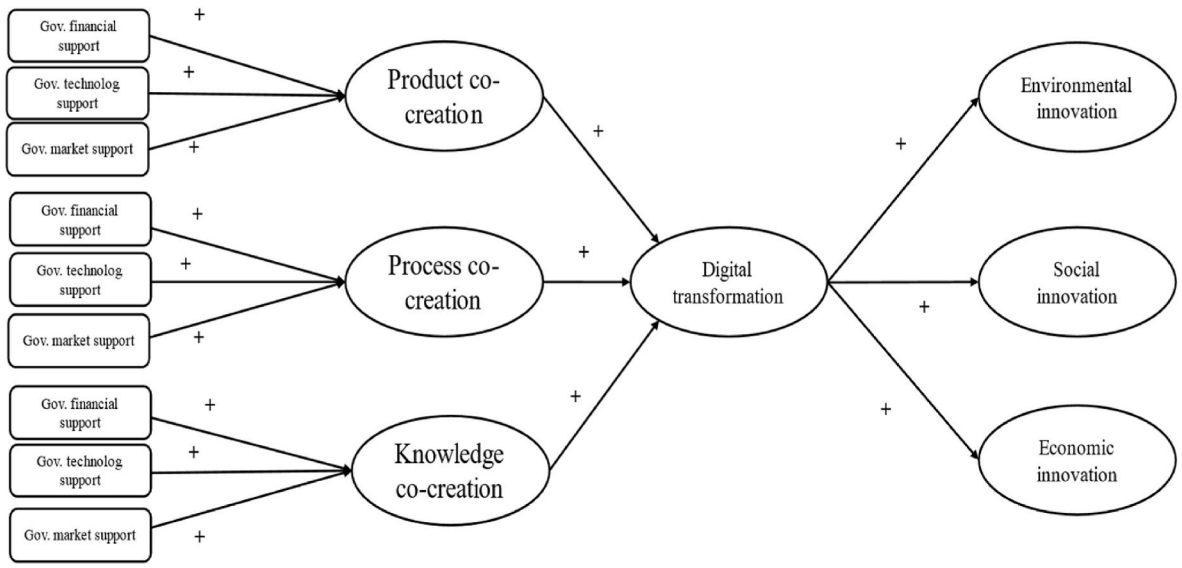


**Fig. 1.** Conceptual model.

the sustainability potential of firms' activities (Nambisan et al., 2017; Tortora et al., 2021; Montakhabi et al., 2023). For instance, there is a large body of literature studying how digital technologies enable circularity practices and the implementation of 3R (reduce, recycle, reuse) principles in manufacturing (Neri et al., 2023; Trevisan et al., 2023).

Even though firms may be able to co-create products, processes and knowledge with external actors, they might not be able to translate such co-creation efforts into sustainable innovation if they do not have the appropriate digital infrastructure and capabilities. Conversely, firms endowed with digital assets can more easily turn their co-creation efforts into sustainable outcomes (Qureshi et al., 2021; Zhao and Qian, 2024).

However, the role of digital transformation is unlikely to be uniform across different forms of co-creation. As discussed above, product, process, and knowledge co-creation differ substantially in their resource configurations, coordination requirements, knowledge characteristics, and the mechanisms through which they generate sustainability outcomes. Therefore, the relevance of digital transformation may depend on the specific form of co-creation involved.

Product co-creation often involves the joint development of new sustainable offerings that must subsequently be scaled, monitored, coordinated, and deployed across value chains in order to generate measurable sustainability outcomes. The translation of collaboratively developed products into environmental, social, and economic benefits frequently requires digitally enabled capabilities such as digital communication channels, data infrastructures, automation systems, traceability mechanisms, and digitally supported coordination tools that connect partners across organisational boundaries (Franzè et al., 2024). Firms engaging in product co-creation but lacking adequate digital infrastructures may therefore encounter difficulties in transforming collaborative product development into tangible sustainability outcomes. Conversely, digitally mature firms may be better positioned to internalise, scale, and deploy the outputs of product co-creation toward sustainable innovation.

Process co-creation primarily operates through the reconfiguration of organisational routines, workflows, and coordination practices among collaborating actors. Sustainability outcomes associated with process co-creation, such as reductions in waste, improvements in energy efficiency, or more inclusive organisational practices, often emerge through organisational learning, behavioural change, and the redesign of operational practices (Chaudhuri et al., 2023; Stojčić et al., 2024). Although digital technologies may facilitate and accelerate these changes, process co-creation does not necessarily depend on digitally mediated infrastructures to generate sustainability benefits. Digital transformation may therefore support process co-creation, but its mediating role is likely to be less systematic than in the case of product co-creation.

In all cases, digital transformation enhances firms' capacity to internalise and exploit the results of co-creation. Hence, we argue that digital transformation of a firm will mediate the relationship between its co-creation efforts and sustainable innovation. We conceptualise sustainable innovation as comprising three dimensions – environmental, social, and economic. Accordingly, we formulate our second set of hypotheses.

**H4**. Digital transformation mediates the positive relationship between product co-creation and sustainable innovation (economic, social and environmental).

**H5**. Digital transformation mediates the positive relationship between process co-creation and sustainable innovation (economic, social and environmental).

**H6**. Digital transformation mediates the positive relationship between knowledge co-creation and sustainable innovation (economic, social and environmental).

Our conceptual model is depicted in Fig. 1.

## 3. Methodology

### 3.1. Data source and collection

A questionnaire survey was developed to collect data to test the relationships in the conceptual model. The questionnaire was first designed in English, as it includes established scales for several variables of interest. It was then translated into French by a bilingual scholar and then back-translated by a professional academic copy-editor, to ensure the reliability of the procedure (Cascio, 2012).

The questionnaire was set up on an online platform and pre-tested on seven respondents from academia and industry. Feedback was used to improve the clarity and reliability of the instrument. The revised instrument was used for the main stage of the data collection. The data collection was assigned to a well-reputed panel data collection company

operating in France during the first half of 2025. The company was instructed to recruit respondents according to criteria designed to ensure representativeness of the French SME population: firms of varying sizes, located across different French regions, and operating in a broad range of industries. The inclusion criteria required that respondents be CEOs or top managers with direct knowledge of their firm's innovation activities, and that firms qualify as SMEs according to the standard European threshold of up to 250 employees. The company maintains access to a large panel of SMEs built to reflect the French SME population along these dimensions, and has an established track record as a data provider for academic and research institutions. The survey instrument that we placed on an internet platform was linked to the data collection company's platform, and we could track the progress of the survey. We were informed that the invitation to take the survey was sent to around 2000 SMEs. Consistent with standard practice in panel-based data collection, detailed information on the full composition of the sampling frame and individual contact details were not disclosed by the panel provider. This precluded the collection of supplementary firm-level data from external sources such as official business registers.

The data collection process lasted six weeks. Attention checks were introduced in several parts of the survey, which led to the termination of the survey for a certain number of respondents, who were not paying sufficient attention to the questions. Introducing attention checks aimed at ensuring the robustness and quality of the data obtained. The respondents of the survey were CEOs and top managers of SMEs operating in a variety of industries (this information is captured through a specific question in the survey) and located all over France (respondents were asked to report the location of their company or its postal code). After eliminating incomplete responses, we obtained a sample of 188 SMEs – companies having up to 250 employees.

The sample is made up of companies of different sizes, with all of them being SMEs. Companies operate in a variety of industries ranging from agriculture to business services, software and others. Several characteristics of the sample and the respondents are presented in the Appendix.

### 3.2. Variables

*Dependent variables:* We used an existing scale developed by Fernandes et al. (2023) to measure sustainable innovation. This scale assesses the extent to which firms have generated environmental, social, and economic benefits through innovation over the past three years. A five-point Likert scale was used to capture the responses. The scale includes items related to *environmental innovation*, *social innovation* and *economic innovation*. Respondents rated the degree to which their firm achieved the benefits from these types of innovation, allowing for a comprehensive measure of sustainable innovation outcomes across multiple dimensions. In our model, we considered each of the dimensions of sustainable innovation separately.

*Independent variables*: Government support was operationalised through three distinct dummy variables, taking the value of 1 if a company has received financial, technological, or market-oriented support from the government in the past three years, and 0 otherwise. This operationalisation reflects the multidimensional nature of government support illustrated in Fig. 1 and allows us to disentangle the effects of different policy instruments on firms' co-creation activities. This operationalisation is fully consistent with the classification of public support instruments adopted in the Community Innovation Survey (CIS), as well as in the literature on innovation policy typologies (Flanagan et al., 2011; Edler and Fagerberg, 2017).

Dichotomous variables (1-yes or 0-no) were used to measure co-creation. Following De Silva and Rossi (2018), three types of co-creation were measured – product co-creation, process co-creation and knowledge co-creation. Three header items were used: (1) In the last three years, has your company developed products with …, (2) In the last three years has your company developed processes with …, (3) In the last three years, has your company been involved in interactive learning and co-development of knowledge (co-development of knowledge refers to the joint creation of new knowledge by two parties) with … The sub-lines for different co-creation partners were then proposed: universities, other firms, clients, consultants, research labs, and suppliers. The measure was operationalised as the sum of these collaborative activities, providing an aggregated score that reflects the breadth of co-creation initiatives undertaken by each firm, in line with Laursen and Salter (2006).

Digital transformation was measured using a scale developed by Al Omoush et al. (2025). A 5-point Likert scale was used to measure the eight items that capture the extent to which firms implement and leverage digital technologies. Respondents indicated their level of agreement with each statement, allowing the scale to quantify the firm's overall level of digital transformation. We calculated an average of the responses for each firm on a 5-point scale.

Table 1 presents the measurements used in the survey.

### 3.3. Data analysis

The analysis began with an evaluation of the measurement model to ensure the reliability and validity of each construct. Indicator loadings, internal consistency metrics, and convergent validity statistics were assessed according to established guidelines. Convergent validity was confirmed through the Average Variance Extracted (AVE), while composite reliability (CR) and Cronbach's alpha values demonstrated satisfactory internal consistency. Discriminant validity was further verified through the Fornell-Larcker criterion, ensuring that each latent construct captured a unique dimension of the model. Multicollinearity diagnostics were also performed, and the Variance Inflation Factors indicated no problematic levels of collinearity among indicators or predictor constructs. Once the measurement model met the recommended psychometric standards, the structural model was estimated to examine the hypothesised causal pathways.

To test the hypothesised relationships among Government Support (financial, market, and technological support), Co-creation (product, process, and knowledge co-creation), Digital Transformation, and Sustainable Innovation (economic, environmental, and social), we applied Partial Least Squares Structural Equation Modelling (PLS-SEM). PLS-SEM was selected because of its suitability for exploratory model testing, its capacity to handle models with both formative and reflective indicators, and its robustness with moderate sample sizes ($N = 188$). In this vein, SEM is an efficient statistical method that allows researchers to analyse complex relationships among multiple variables through the estimation of both measurement and structural models (Hair et al., 2019).

To evaluate the structural model, we examined the significance and direction of the path coefficients estimated through Stata. The significance levels were assessed using bootstrapped standard errors, z-statistics and their corresponding confidence intervals, which allowed us to determine whether each relationship was supported by the data. This approach provided a robust basis for hypothesis testing, given that the bootstrapped standard errors generated stable estimates for each coefficient. The interpretation focused on the magnitude and statistical significance of the effects linking government support to the three forms of co-creation, as well as the subsequent effects of co-creation on digital transformation and its influence on sustainable innovation. All analyses were conducted using Stata (version 18), ensuring the reproducibility and reliability of the statistical procedures applied in this study.

To further assess the robustness of the findings, additional analyses were conducted. First, the models were re-estimated after excluding organisations operating in the financial sector to verify whether the results were sensitive to sector-specific effects. Second, the model was re-estimated using heteroskedasticity-robust standard errors (vce (robust)).

**Table 1**
Variables and measurements.

| Variable | Measurement | Source |
|---|---|---|
| Government financial support | Dummy variable taking the value 1 if the company received financial support from the government in the last 3 years, and 0 otherwise. | Authors, following Flanagan et al. (2011), Edler and Fagerberg (2017), and Community Innovation Survey (CIS) |
| Government technological support | Dummy variable taking the value 1 if the company received technological support from the government in the last 3 years, and 0 otherwise. | Authors, following Flanagan et al. (2011), Edler and Fagerberg (2017), and Community Innovation Survey (CIS) |
| Government market support | Dummy variable taking the value 1 if the company received market support from the government in the last 3 years, and 0 otherwise. | Authors, following Flanagan et al. (2011), Edler and Fagerberg (2017), and Community Innovation Survey (CIS) |
| Product co-creation | Dichotomous variables (yes-no) used to measure whether the company engaged in product co-creation with: universities, other firms, clients, consultants, research labs, suppliers in the last three years. The measure was operationalised as the sum of these collaborative activities. | De Silva and Rossi (2018) Laursen and Salter (2006) |
| Process co-creation | Dichotomous variables (yes-no) used to measure whether the company engaged in process co-creation with: universities, other firms, clients, consultants, research labs, suppliers in the last three years. The measure was operationalised as the sum of these collaborative activities. | De Silva and Rossi (2018) Laursen and Salter (2006) |
| Knowledge co-creation | Dichotomous variables (yes-no) used to measure whether the company engaged in knowledge co-creation with: universities, other firms, clients, consultants, research labs, suppliers in the last three years. The measure was operationalised as the sum of these collaborative activities. | De Silva and Rossi (2018) Laursen and Salter (2006) |
| Digital transformation | A 5-point Likert scale, 8 items: (1) Digital transformation is a high-value continual business strategy in my firm; (2) My firm regularly updates its IT infrastructure; (3) My firm continually analyzes possibilities of digitizing new processes with emerging new digital innovations; (4) A digitalization mindset is generally embedded in my firm culture; (5) We are constantly seeking to acquire new knowledge-related digitalization; (6) My firm pursues new digital innovations alongside its business operations; (7) The degree of automation in my firm's processes and services is high; (8) Management believes that the best way to reach customers is through digital channels. | Al Omoush et al. (2025) |
| Environmental innovation | A 5-point Likert scale assessing the extent to which the firm has generated environmental benefits through product, process, organisational or any type of innovation over the past three years. | Fernandes et al. (2023) |
| Social innovation | A 5-point Likert scale assessing the extent to which the firm has generated social benefits through product, process, organisational or any type of innovation over the past three years. | Fernandes et al. (2023) |
| Economic innovation | A 5-point Likert scale assessing the extent to which the firm has generated economic benefits through product, process, organisational or any type of innovation over the past three years. | Fernandes et al. (2023) |

## 4. Results

### 4.1. Results of the main analysis

Table 2 reports the descriptive statistics of the variables included in the analysis. The three types of government support (financial, technological, and market) exhibit mean values of 0.88, 0.34, and 0.36 respectively, reflecting a relatively high presence of financial support, but substantially lower prevalence of technology and market support within the sample. The three co-creation dimensions (product, process, and knowledge) show relatively low frequencies overall, although with substantial variability (standard deviations between 1.62 and 1.72), indicating heterogeneous levels of co-creation engagement across firms. This dispersion suggests that collaborative innovation practices are present but not uniformly developed in the observed firms.

Regarding the focal constructs, the average level of Digital Transformation is 3.17 (SD = 1.06) on a five-point scale, meaning that firms demonstrate a moderate level of digital transformation maturity, with some variation but no clustering at extreme scale points. Additionally, the descriptive results show relatively low mean levels of sustainable innovation across environmental (0.30), social (0.27), and economic (0.39) dimensions, with substantial variability among firms. All three indicators range from 0 to 1, reflecting their operationalisation as outcome measures of innovation benefits. Overall, the economic

**Table 2**
Descriptive statistics.

| Variable | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Gov. support (financial) - GOVF | 0.88 | 0.32 | 0.00 | 1.00 |
| Gov. support (technol.) - GOVT | 0.34 | 0.47 | 0.00 | 1.00 |
| Gov. support (market) - GOVM | 0.36 | 0.48 | 0.00 | 1.00 |
| Co-creation (product) - COPR | 1.70 | 1.72 | 0.00 | 6.00 |
| Co-creation (process) - COPC | 1.31 | 1.66 | 0.00 | 6.00 |
| Co-creation (knowledge) - COK | 0.92 | 1.62 | 0.00 | 6.00 |
| Digital transformation - DIGTR | 3.17 | 1.06 | 1.00 | 5.00 |
| Sustainable innovation - ENV | 0.30 | 0.40 | 0.00 | 1.00 |
| Sustainable innovation - SOC | 0.27 | 0.37 | 0.00 | 1.00 |
| Sustainable innovation - ECO | 0.39 | 0.40 | 0.00 | 1.00 |

Source: Authors' work.

dimension is slightly more prevalent, while environmental and social innovations have lower values.

Table 3 presents the correlation values in the off-diagonal. All correlations were below the threshold of 0.85, indicating that multicollinearity was not a concern in this study. To further confirm the absence of multicollinearity, the Variance Inflation Factor (VIF) was also examined, with all values ranging from 1.04 to 2.03, well below the recommended cutoff value of 10.

In the diagonal of the correlation matrix, the square roots of the AVE values are reported for the four latent constructs: Digital Transformation ($\sqrt{AVE} = 0.836$), Sustainable Innovation Env ($\sqrt{AVE} = 0.813$), Sustainable Innovation Soc ($\sqrt{AVE} = 0.776$) and Sustainable Innovation Eco ($\sqrt{AVE} = 0.749$). These values were used to assess discriminant validity following the Fornell-Larcker criterion. Variables that are either binary or single-item measures were excluded from this analysis, as AVE and its square root can only be computed for constructs with multiple items. Consequently, the Fornell-Larcker criterion was applied exclusively to the two multi-item latent constructs. All the diagonal values were greater than the corresponding values in rows and columns, which confirmed the discriminant validity (Fornell and Larcker, 1981).

In line with Anderson and Gerbing's (1988) recommendation, this study employed a two-step procedure, comprising measurement and structural models. The measurement model was used to assess the reliability and validity of the latent variables, while the structural model examined the hypothesised relationships among them.

As shown in Table 4, the latent constructs demonstrated satisfactory reliability, with all Cronbach's alpha and composite reliability values surpassing the 0.70 threshold suggested by Fornell and Larcker (1981). The AVE scores, ranging from 0.561 to 0.699, met the minimum criterion of 0.5, and factor loadings between 0.73 and 0.89 were above the 0.70 standard, confirming convergent validity.

Table 5 displays the results of the hypotheses' testing. The results indicate that government technological support positively affects product co-creation by SMEs ($\beta = 1.077$, $p < 0.10$), supporting hypothesis H2a. No other forms of government support are significantly associated with product co-creation. We also find that product co-creation has a positive influence on digital transformation ($\beta = 0.28$, $p < 0.01$). Digital transformation increases sustainable innovation in companies across all their individual dimensions: environmental ($\beta = 0.17$, $p < 0.01$), social ($\beta = 0.14$, $p < 0.01$) and economic ($\beta = 0.18$, $p < 0.01$). This supports hypothesis H4, as we demonstrate that there is a mediating effect of digital transformation in the positive relationship between product co-creation and sustainable innovation. The influence of government support on process co-creation is not significant. Hypotheses H1b, H2b and H3b are thus not supported. Process co-creation is not significantly related to digital transformation, thus rejecting hypothesis H5. When it comes to knowledge co-creation, it is positively affected only by government market support ($\beta = 1.72$, $p < 0.01$), supporting hypothesis H3c. However, there is no significant relationship between knowledge co-creation and digital transformation. The mediation effect cannot be supported. Hypothesis H6 is thus not supported.

Fig. 2 shows the results of the PSL-SEM analysis for our conceptual model.

**Table 4**
Reliability and validity.

| Constructs | Items | Loadings | Cronbach's alpha | Composite reliability | Average variance extracted |
|---|---|---|---|---|---|
| DIGTR | dig1 | 0.8872 | 0.949 | 0.949 | 0.699 |
| | dig2 | 0.8019 | | | |
| | dig3 | 0.8977 | | | |
| | dig4 | 0.8507 | | | |
| | dig5 | 0.8462 | | | |
| | dig6 | 0.8738 | | | |
| | dig7 | 0.7743 | | | |
| | dig8 | 0.7455 | | | |
| SUSIN | esi1 | 0.8022 | 0.891 | 0.887 | 0.661 |
| | esi2 | 0.8802 | | | |
| | esi3 | 0.8106 | | | |
| | esi4 | 0.7538 | | | |
| | ssi1 | 0.7772 | 0.870 | 0.858 | 0.602 |
| | ssi2 | 0.7821 | | | |
| | ssi3 | 0.7540 | | | |
| | ssi4 | 0.7888 | | | |
| | ecsi1 | 0.7522 | 0.848 | 0.837 | 0.561 |
| | ecsi2 | 0.7357 | | | |
| | ecsi3 | 0.7331 | | | |
| | ecsi4 | 0.7750 | | | |

Note: Co-creation and government support variables are dichotomous (yes/no) and do not use the Likert scale; hence, they are not included in this table.
Source: Authors' work.

### 4.2. Supplementary analyses

Having found no mediation effect of digital transformation for process and knowledge co-creation, we tested whether these types of co-creation are directly positively related to sustainable innovation. We find support for both direct relationships – both process and knowledge co-creation positively affect sustainable innovation. The test confirms that process co-creation has a positive and direct impact on sustainable innovation across all its individual dimensions: environmental ($\beta = 0.08$, $p < 0.01$), social ($\beta = 0.05$, $p < 0.10$) and economic ($\beta = 0.05$, $p < 0.10$). In turn, knowledge co-creation has a positive and direct impact on two dimensions: environmental ($\beta = 0.06$, $p < 0.05$) and social ($\beta = 0.07$, $p < 0.01$). In other words, the mediation of digital transformation is not necessary between the co-creation of processes and knowledge and sustainable innovation. Consequently, there is only partial mediation of digital transformation; its mediation effect is limited to the relationship between product co-creation and sustainable innovation.

**Table 3**
Correlation and multicollinearity test.

| Variable | VIF | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) GOVF | 1.04 | 1.00 | | | | | | | | | |
| (2) GOVT | 1.38 | −0.124 | 1.00 | | | | | | | | |
| (3) GOVM | 1.28 | 0.020 | 0.429*** | 1.00 | | | | | | | |
| (4) COPR | 1.52 | 0.060 | 0.323** | 0.295** | 1.00 | | | | | | |
| (5) COPC | 1.29 | 0.116 | 0.182 | 0.273* | 0.775*** | 1.00 | | | | | |
| (6) COK | 1.52 | 0.182 | 0.269* | 0.457*** | 0.676*** | 0.675*** | 1.00 | | | | |
| (7) DIGTR | 1.51 | 0.072 | 0.337*** | 0.253* | 0.495*** | 0.429*** | 0.426*** | 0.836 | | | |
| (8) ENV | 1.85 | 0.285** | 0.166 | 0.318** | 0.595*** | 0.603*** | 0.576*** | 0.441*** | 0.813 | | |
| (9) SOC | 2.03 | 0.127 | 0.329*** | 0.433*** | 0.633*** | 0.582*** | 0.630*** | 0.490*** | 0.717*** | 0.776 | |
| (10) ECO | 1.72 | 0.058 | 0.420*** | 0.326** | 0.586*** | 0.544*** | 0.542*** | 0.546*** | 0.654*** | 0.728*** | 0.749 |

Note: ***p < 0.01. **p < 0.05. *p < 0.10.
Source: Authors' work.

**Table 5**
SEM models.

| Models | β (coefficient) | Std. err. | z | C.I. [lower bound] | C.I. [upper bound] |
|---|---|---|---|---|---|
| D.V.: Co-creation (product) | | | | | |
| GOVF | 0.543 | 0.812 | 0.67 | −1.048 | 2.136 |
| GOVT | 1.077* | 0.617 | 1.75 | −0.132 | 2.286 |
| GOVM | 0.761 | 0.604 | 1.26 | −0.422 | 1.946 |
| D.V.: Co-creation (process) | | | | | |
| GOVF | 0.751 | 0.819 | 0.92 | −0.855 | 2.358 |
| GOVT | 0.414 | 0.622 | 0.67 | −0.805 | 1.634 |
| GOVM | 0.928 | 0.609 | 1.52 | −0.266 | 2.123 |
| D.V.: Co-creation (knowledge) | | | | | |
| GOVF | 1.202 | 0.785 | 1.53 | −0.336 | 2.741 |
| GOVT | 0.524 | 0.596 | 0.88 | −0.643 | 1.693 |
| GOVM | 1.726*** | 0.583 | 2.96 | 0.581 | 2.870 |
| D.V.: Digital transformation | | | | | |
| COPR | 0.285*** | 0.115 | 2.48 | 0.059 | 0.510 |
| COPC | −0.003 | 0.106 | −0.04 | −0.212 | 0.204 |
| COK | 0.010 | 0.099 | 0.11 | −0.184 | 0.206 |
| D.V.: Sustainable innovation (Env) | | | | | |
| DIGTR | 0.173*** | 0.041 | 4.20 | 0.092 | 0.254 |
| COPR | −0.030 | 0.035 | −0.84 | −0.100 | 0.039 |
| COPC | 0.084*** | 0.031 | 2.71 | 0.023 | 0.145 |
| COK | 0.062** | 0.029 | 2.13 | 0.005 | 0.119 |
| D.V.: Sustainable innovation (Soc) | | | | | |
| DIGTR | 0.146*** | 0.041 | 3.51 | 0.064 | 0.227 |
| COPR | −0.011 | 0.035 | −0.32 | −0.081 | 0.058 |
| COPC | 0.056* | 0.031 | 1.8 | −0.005 | 0.117 |
| COK | 0.078*** | 0.029 | 2.66 | 0.020 | 0.136 |
| D.V.: Sustainable innovation (Eco) | | | | | |
| DIGTR | 0.185*** | 0.046 | 3.96 | 0.093 | 0.276 |
| COPR | 0.012 | 0.040 | 0.31 | −0.066 | 0.091 |
| COPC | 0.059* | 0.035 | 1.69 | −0.009 | 0.128 |
| COK | 0.035 | 0.033 | 1.06 | −0.029 | 0.099 |

Note: D.V. Dependent variable.
Source: Authors' work.

Financial companies follow a different type of legislation, which may influence their sustainability performance. Therefore, we conducted a robustness analysis excluding the financial companies from the sample (6 companies) to verify the consistency of the data. Overall, the signs and significance remained stable, except for one relationship. As shown in Table 6, the data reveal that government financial support affects the co-creation of knowledge in French SMEs ($\beta = 1.52$, $p < 0.10$). As an additional robustness check, the model was re-estimated using heteroskedasticity-robust standard errors (vce(robust)). The results remained substantially unchanged, with coefficients preserving their direction, magnitude, and statistical significance. These findings suggest that the reported relationships are not sensitive to potential heteroskedasticity issues.

The summary of hypotheses and the results of the hypotheses' tests are presented in Table 7.

Fig. 3 depicts the adjusted model, highlighting the confirmed direct positive relationship between process co-creation and the three

**Table 6**
Robustness test: excluding financial companies.

| Models | β (coefficient) | Std. err. | z | C.I. [lower bound] | C.I. [upper bound] |
|---|---|---|---|---|---|
| D.V.: Co-creation (product) | | | | | |
| GOVF | 0.766 | 0.901 | 0.85 | −1.000 | 2.534 |
| GOVT | 1.093* | 0.646 | 1.69 | −0.174 | 2.361 |
| GOVM | 0.504 | 0.637 | 0.79 | −0.744 | 1.754 |
| D.V.: Co-creation (process) | | | | | |
| GOVF | 1.047 | 0.890 | 1.18 | −0.698 | 2.793 |
| GOVT | 0.436 | 0.639 | 0.68 | −0.816 | 1.688 |
| GOVM | 0.587 | 0.629 | 0.93 | −0.647 | 1.822 |
| D.V.: Co-creation (knowledge) | | | | | |
| GOVF | 1.520* | 0.859 | 1.77 | −0.163 | 3.205 |
| GOVT | 0.576 | 0.616 | 0.93 | −0.632 | 1.784 |
| GOVM | 1.402** | 0.607 | 2.31 | 0.211 | 2.594 |
| D.V.: Digital transformation | | | | | |
| COPR | 0.283*** | 0.118 | 2.39 | 0.050 | 0.516 |
| COPC | −0.009 | 0.118 | −0.08 | −0.240 | 0.222 |
| COK | 0.007 | 0.104 | 0.07 | −0.197 | 0.211 |
| D.V.: Sustainable innovation (Env) | | | | | |
| DIGTR | 0.176*** | 0.042 | 4.19 | 0.093 | 0.258 |
| COPR | −0.032 | 0.036 | −0.89 | −0.102 | 0.038 |
| COPC | 0.089*** | 0.031 | 2.80 | 0.026 | 0.151 |
| COK | 0.066** | 0.029 | 2.23 | 0.007 | 0.124 |
| D.V.: Sustainable innovation (Soc) | | | | | |
| DIGTR | 0.150*** | 0.042 | 3.57 | 0.067 | 0.233 |
| COPR | −0.011 | 0.036 | −0.33 | −0.083 | 0.059 |
| COPC | 0.058* | 0.032 | 1.81 | −0.004 | 0.120 |
| COK | 0.079*** | 0.029 | 2.65 | 0.020 | 0.138 |
| D.V.: Sustainable innovation (Eco) | | | | | |
| DIGTR | 0.187*** | 0.047 | 3.94 | 0.094 | 0.280 |
| COPR | 0.010 | 0.040 | 0.26 | −0.069 | 0.090 |
| COPC | 0.063* | 0.036 | 1.77 | −0.006 | 0.134 |
| COK | 0.038 | 0.033 | 1.15 | −0.027 | 0.105 |

Note: D.V. Dependent variable.
Source: Authors' work.

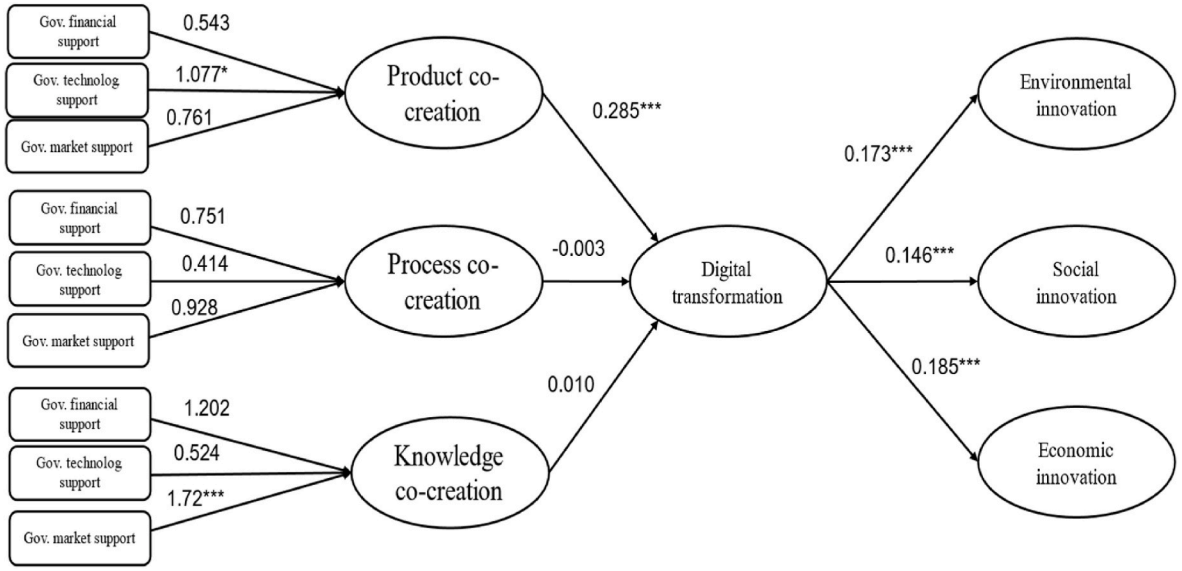


**Fig. 2.** Results of the main analysis.

**Table 7**
Results of the hypotheses' testing.

| Hypothesis | Result |
|---|---|
| H1a. Financial government support has a positive effect on product co-creation. | Not supported |
| H1b. Financial government support has a positive effect on process co-creation. | Not supported |
| H1c. **Financial government support has a positive effect on knowledge co-creation.** | **Partially supported (supported for a sample without financial companies)** |
| H2a. **Technological government support has a positive effect on product co-creation.** | **Supported** |
| H2b. Technological government support has a positive effect on process co-creation. | Not supported |
| H2c. Technological government support has a positive effect on knowledge co-creation. | Not supported |
| H3a. Market government support has a positive effect on product co-creation. | Not supported |
| H3b. Market government support has a positive effect on process co-creation. | Not supported |
| H3c. **Market government support has a positive effect on knowledge co-creation.** | **Supported** |
| H4. **Digital transformation mediates the positive relationship between product co-creation and sustainable innovation (economic, social and environmental).** | **Supported** |
| H5. Digital transformation mediates the positive relationship between process co-creation and sustainable innovation (economic, social and environmental). | Not supported |
| H6. Digital transformation mediates the positive relationship between knowledge co-creation and sustainable innovation (economic, social and environmental). | Not supported |

dimensions of sustainable innovation, as well as between knowledge co-creation and social and environmental innovation.

## 5. Discussion

Co-creation with external constituents is an open innovation process with strong potential to generate sustainable innovation and derive environmental, social, and economic benefits (McGahan et al., 2021; Chesbrough et al., 2024). However, the conditions under which different forms of co-creation emerge, and the mechanisms through which they translate into sustainability outcomes, are far from uniform. Our empirical analysis, conducted on 188 SMEs in France, produces a nuanced picture that both confirms and complicates existing assumptions in the literature. First, it appears that government assistance plays a much smaller role than the literature would lead us to expect. In fact, the technological support of the government has a positive impact on product co-creation, and market support on knowledge co-creation. We also find a positive effect of financial support on knowledge co-creation, when we exclude financial companies from the sample. Thus, of the nine hypotheses linking financial, technological, and market support to the three forms of co-creation, only two are fully supported and one is partially supported. This pattern, however, is not random. Instead, it follows the logic of the differentiated theoretical framework developed in this study, and its interpretation reveals important insights about the nature of co-creation and its enabling conditions.

The confirmation that technological support positively affects product co-creation is consistent with the argument that collaborative product development requires complementary technical competences and interfaces for joint experimentation and testing, often facilitated by innovation intermediaries (Howells, 2006; De Silva and Rossi, 2018; Caloffi et al., 2023; Colovic et al., 2024). This issue is the subject of debate in the literature on innovation intermediaries, which suggests that not all forms of intermediation are equivalent and that technologically oriented intermediaries may be particularly effective at enabling the kind of codifiable, infrastructure-dependent collaboration that characterises product co-creation. A plausible interpretation lies in the nature of the resources mobilised by different policy instruments rather than in the sheer availability of support. Financial constraints are not always the most binding obstacles to innovation; firms frequently face shortages of knowledge, skills, and capabilities, as well as difficulties in identifying suitable partners and technological opportunities (Galia and Legros, 2004; D'Este et al., 2012; Iammarino et al., 2021). Moreover, enabling co-creation often requires soft capacities – facilitation, brokering, translation of frameworks into actionable knowledge, and modular, tailored support – in addition to funding (Alvial Palavicino et al., 2023; Chaudhuri et al., 2023).

The confirmation that market support positively affects knowledge co-creation is equally consistent with the theoretical framework and points to a mechanism that has received relatively little attention in the policy literature. Many of these tools have a specific commercial purpose, namely to expand or create markets in which businesses can sell their products or services. To achieve this aim, market-oriented instruments operate primarily by reducing institutional uncertainty, creating shared market expectations, and legitimising new sustainability-oriented solutions. These are precisely the enabling conditions for knowledge co-creation among heterogeneous actors, whose collaboration depends less on financial or technical resources and more on the alignment of interpretive frameworks, the development of mutual trust, and the emergence of shared cognitive maps. In other words, the sustainability-oriented networking function of market support instruments may be at least as important as their more visible commercial function.

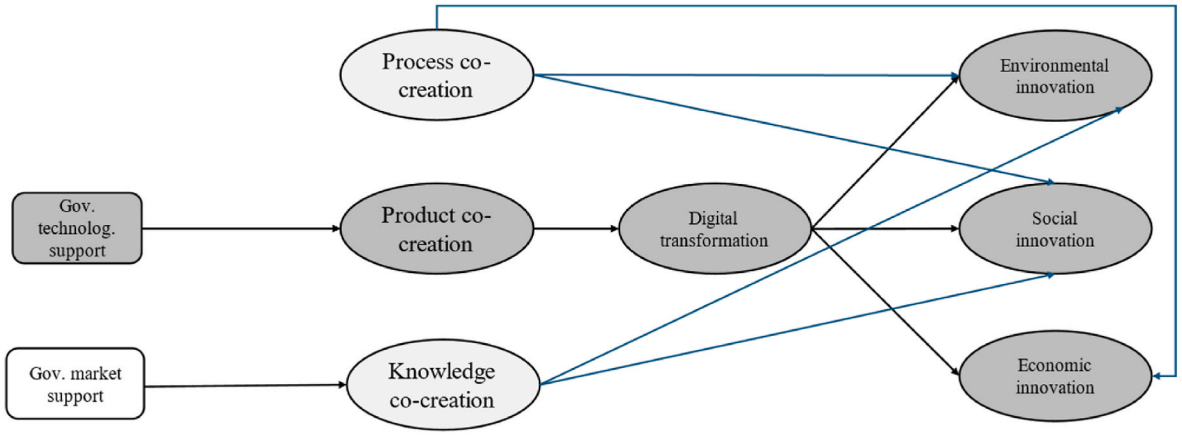


**Fig. 3.** The confirmed relationships in the model.

By contrast, no form of government support is found to significantly affect process co-creation. We believe that this finding may be explained by the fact that while technological support is often designed to enhance firms' access to new technologies and technical expertise, process innovation typically involves deep organisational change, routinisation, and context-specific adaptation that extend beyond the provision of technological assets alone (Stojčić et al., 2024). Process co-creation frequently requires the reconfiguration of workflows, roles, and coordination mechanisms within the firm, as well as the alignment of organisational practices across collaborating partners (Baptista, 1999; Damanpour and Aravind, 2006). These changes depend not only on technological capabilities, but also on managerial skills, organisational learning, and the ability to negotiate and stabilise new routines. As a result, technological support may be insufficient to trigger process co-creation if it is not complemented by organisational, managerial, or relational forms of support (Chaudhuri et al., 2023).

More broadly, the relatively lower impact of government support than expected can also be explained by the fact that companies, in particular SMEs, often rely on informal networks to gain knowledge, develop new products and processes, as documented in prior research. Abreu et al. (2008) emphasise personal relationships and the development of mutual trust over time, as stimulators of collaborative innovation. Martin-Rios et al. (2022) find that small innovative firms gain advantages from informal knowledge networks. To establish such networks, they might not need government support in any form. Howells et al. (2012) analyse barriers to collaboration between firms and universities and show that while firms are reluctant to collaborate with universities, when they do put in place such collaborations, their innovative performance improves significantly. Because of the many perceived barriers to co-creation with universities, firms might not be willing to engage in such processes, even though governments might provide them with incentives to do so. Overcoming perceptual obstacles to co-creation by the firm itself could be a stronger conduit to co-creation than the incentives provided by the government.

A second major contribution of this study concerns the heterogeneous pathways through which different forms of co-creation translate into sustainability outcomes, and the asymmetric role played by digital transformation along these pathways. The finding that digital transformation mediates the relationship between product co-creation and sustainable innovation, but does not play a role as mediator for process or knowledge co-creation, suggests that digital transformation does not operate as a generic enabler of sustainable innovation, but rather as a capability that is specifically relevant when sustainability outcomes depend on the scaling, deployment, monitoring, and coordination of the collaborative efforts made by various stakeholders throughout the value chain to produce a good or service. Product co-creation may generate prototypes or new offerings, but transforming these into sustainability outcomes requires digitally enabled scaling and market deployment. For example, digital channels may be needed to reach customers, data infrastructures to monitor product performance, automation and IT integration to ensure quality and traceability, or digitally supported coordination tools to connect partners (Franzè et al., 2024). These digitally enabled infrastructures are not merely tools that make production more efficient, but they are constitutive components of the innovation itself: without them, the sustainability potential of co-created products may remain unrealised (Nambisan et al., 2017; Franzè et al., 2024).

For process and knowledge co-creation, by contrast, the pathways to sustainability outcomes appear to operate through different mechanisms. Prior research suggests that collaborative innovation processes often generate sustainability outcomes through the reconfiguration of organisational routines, coordination practices, and relational learning mechanisms, rather than through digitally mediated infrastructures. In particular, process-oriented forms of co-creation tend to operate through embedded changes in workflows and operational practices, which rely heavily on tacit knowledge and organisational learning (Chaudhuri et al., 2023; Stojčić et al., 2024). From an information-processing perspective, digital transformation may support such changes, but it is not a necessary condition for process-level innovation to translate into environmental, social, and economic benefits. In the case of knowledge co-creation, the absence of digital mediation reflects the fact that joint knowledge creation primarily involves the exchange of tacit, experience-based knowledge, as well as shared understanding and problem framing, which emerge through interaction rather than through codified or digitally mediated processes (De Silva et al., 2021b). These processes support environmental and social innovation by shaping firms' practices and legitimacy, while economic returns typically require additional stages of transformation, such as the development of new products, processes, or business models, and may therefore emerge only over longer time horizons (Goyal et al., 2020).

## 6. Conclusions

Whether and how co-creation, as an open innovation process, leads to sustainable innovation are important, yet under-researched issues in the academic literature. One of the key findings of our work is that co-creation does not lead to sustainable innovation through a single mechanism, but rather through distinct collaborative approaches that vary in terms of the resources required, coordination mechanisms and enabling conditions. Recognising this heterogeneity is essential both from a theoretical perspective, which has tended to treat co-creation as a relatively undifferentiated concept, and in practice, where managers and policymakers need to understand which forms of co-creation are relevant to which sustainability objectives and what enabling conditions are required for each of them.

### 6.1. *Implications for literature*

Our findings contribute to open innovation, innovation policy and sustainability literature in two main ways. First, we demonstrate that the effects of government support on co-creation are not uniform, but are contingent on the specific form of co-creation and the type of policy instrument involved: different instruments address different barriers, and their effectiveness depends on the alignment between what the instrument provides and what a given form of co-creation actually requires. While technological support helps with product co-creation and market support helps with knowledge co-creation, our findings suggest that SMEs have an interest in engaging in co-creation regardless of the support of the government. This suggests that SMEs are aware of the benefits that open innovation efforts can bring them and that they are ready to commit resources to such efforts. This has broader implications for how innovation policy is theorised: rather than asking whether government support stimulates open innovation in general, the field needs more differentiated frameworks that account for the heterogeneity of collaborative configurations and their enabling conditions (De Silva, 2025). Second, we demonstrate that three kinds of co-creation, as identified by De Silva and Rossi (2018), all lead to sustainable innovation, although they take somewhat different paths to do so. While product co-creation requires digital transformation as a mediating capability to realise the sustainability potential of jointly developed products, process and knowledge co-creation directly yield sustainable innovation. These are novel and original findings, allowing us to advance both open innovation and sustainability literature streams. These findings contribute to the emerging literature on the twin transition by showing that the connection between digital and sustainability transitions is specific to the domain of product co-creation, and less

relevant for other collaborative pathways. At the same time, by demonstrating that all three forms of co-creation lead to sustainable innovation, we stress the importance of treating co-creation as a central mechanism in sustainability transitions.

### 6.2. Implications for policy and practice

This study has important practical implications for SMEs and also for policymakers. When it comes to SMEs, they should be aware of the potential of co-creation efforts to generate sustainable innovation. Making use of complementary competencies and skills of external partners, such as suppliers, clients or universities, can generate outcomes that are not only beneficial to the firm, but also to society in general.

As for policymakers, they should select policy instruments based on the specific type of co-creation they aim to foster. Technological support should be prioritised where the policy objective is to stimulate the collaborative development of sustainable products. Market support appears particularly effective in fostering knowledge co-creation, and for this reason, should be a particularly useful tool for stimulating the formation of sustainability-oriented ecosystems. Finally, if the objective is to stimulate process co-creation, standard financial or technological incentives are not sufficient. In this case, more organisation-oriented interventions may be necessary, such as facilitated peer-learning programmes or forms of support for managerial development.

### 6.3. Limitations and directions for future research

Our study presents certain limitations, which open avenues for future research. Our sample is limited in size and is made up of only French SMEs. We can therefore not claim the generalizability of our findings to larger firms and firms located in other settings. For example, it is plausible that in some other settings, such as developing countries, a greater role of government support in stimulating co-creation could be observed. Similarly, a stronger effect of digital transformation could also be found in such settings. It would therefore be interesting to examine the relationships studied in this research in other countries. In addition, in this research, we studied co-creation with (six kinds of) external constituents at an aggregate level. Future research could investigate whether and how co-creation with each type of external constituent leads to sustainable innovation outcomes.

Furthermore, the data used in this study is self-reported, which carries potential biases associated with such type of data. Last, but not least, we used an established scale for digital transformation, which estimates the overall digital transformation of a company, covering digital skills, processes and infrastructure. It would be interesting to examine whether the adoption of specific digital technologies (such as AI, cloud, blockchain or others) plays a role in the process of creating sustainable innovation. Future studies could also complement the PLS-SEM approach adopted in this study with alternative analytical techniques, such as Necessary Condition Analysis (NCA) and Fuzzy-Set Qualitative Comparative Analysis (fsQCA). While PLS-SEM is appropriate for examining net effects among constructs, NCA and fsQCA may provide additional insights into necessary conditions and configurational combinations associated with sustainable innovation outcomes.

## CRediT authorship contribution statement

**Ana Colovic:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. **Annalisa Caloffi:** Conceptualization, Formal analysis, Investigation, Methodology, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. **Alan Bandeira Pinheiro:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

## Declaration of conflict of interest

The authors have no conflict of interest to declare.

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## Appendix I. Characteristics of the companies and of the respondents

| SMEs | | Respondents | |
|---|---|---|---|
| Age (in years) | | Education | |
| Up to 10 | 6 (3.19%) | High school | 5 (2.65%) |
| 10-20 | 2 (1.06%) | College diploma | 31 (16.48%) |
| 20-30 | 3 (1.59%) | Undergraduate bachelors | 47 (25%) |
| 30-40 | 4 (2.12%) | Postgraduate masters | 71 (37.76%) |
| 40-50 | 3 (1.59%) | PhD or DBA | 15 (7.97%) |
| >50 years | 170 (90.42%) | Other | 19 (10.10%) |
| Size (employees) | | Job tenure (in years) | |
| Up to 20 | 86 (45.74%) | Up to 5 | 74 (39.36%) |
| 20-100 | 60 (31.91%) | 5-10 | 50 (26.59%) |
| 100-200 | 26 (13.82%) | 10-15 | 32 (17.02%) |
| > 200 < 250 | 16 (8.51%) | 15-20 | 12 (6.38%) |
| | | > 20 | 20 (10.63%) |
| Company type | | Gender | |
| Family owned | 59 (31.38%) | Female | 97 (51.59%) |
| Privately owned | 107 (56.91%) | Male | 90 (47.87%) |
| State owned | 18 (9.57%) | Non-binary/third gender | 1 (0.53%) |

(*continued on next page*)

(*continued*)

| SMEs | Respondents | |
|---|---|---|
| Listed on a stock market | 4 (2.12%) | |
| Sector | Number of companies | Frequency (%) |
| Agriculture, forestry, or fishing | 5 | 2.66 |
| Business services (e.g., consultancy) | 28 | 14.89 |
| Construction | 21 | 11.17 |
| Finance, banking, or insurance | 6 | 3.19 |
| Health services | 8 | 4.26 |
| Hotel and leisure | 17 | 9.04 |
| Legal services | 4 | 2.13 |
| IT, software and communications | 14 | 7.45 |
| Manufacturing | 13 | 6.91 |
| Mining and extraction | 2 | 1.06 |
| Pharmaceuticals | 1 | 0.53 |
| Retail | 20 | 10.64 |
| Transportation and distribution | 3 | 1.60 |
| Utilities | 2 | 1.06 |
| Other | 44 | 23.40 |
| Total | 188 | 100.00 |

Source: Authors' work.

## Data availability

The data that has been used is confidential.

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