Unconventional path dependence: how adopting product take-back and recycling systems contributes to future eco-innovations

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Abstract

Eco-innovation (EI) allows organizations to achieve environmental and economic gains but the conditions for successful EI to occur are unclear. This paper proposes that firms can improve their EI performance by adopting circular economy (CE) systems and technologies, such as product take-back and recycling. We thus explore an unconventional, systems- and technology-driven path dependence dynamic leading to higher EI performance because of prior CE commitments (instead of managerial initiatives directly aimed at fostering EI). An analysis of 724 firms shows that the adoption of such technologies and systems puts firms on a sustainability path: firms benefit from making further changes to improve the functioning of these systems, which in turn create the conditions and capabilities for future EIs. Environmental supply chain policies thus mediate the relationship as the firm adopting take-back and recycling needs to involve outside partners in their administration. Neither environmental management systems nor data protection policies act as mediators. This is the first quantitative study that considers take-back and recycling and EI scores with a cross-national-cross-sectorial sample size. The results indicate that firms should see the introduction of CE systems and technologies as an opportunity for EI.

Keywords: Eco-innovation, Circular economy, Environmental supply chains, Environmental management systems

1. Introduction

Achieving further economic development and improved living standards for a population expected to reach 10 billion by 2050 is one of the most pressing challenges of our time (OECD, 2012). Past economic progress has come at the expense of diminishing natural resources, increasing pollution, and widespread damage to ecosystems across the globe (UNEP, 2019). Much research has been done to explore potential remedies to these issues (Fehrer and Wieland, 2021), and two central concepts are the circular economy (CE) and eco-innovation (EI).

The CE seeks to 'close the loops' of wasteful material flow and envisions a resilient and regenerative economy that can cycle materials perpetually with minimal pollution (EMF, 2012). Closing the myriad of open loops requires efforts by public and private actors (Witjes and Lozano, 2016). The CE has therefore branched out to look at all stages of products' life cycles to achieve improvements (Su et al., 2013). Several mechanisms are proposed here. Kirchherr et al. (2017) review 114 definitions of the CE and find that among the concept's four mechanisms, 'recycle' is the most commonly cited (following by 'reuse,' 'reduce,' and 'recover'), and that these require cooperation across the boundaries of individual organizations. These authors also find that the CE's aims and enablers are more diverse than adherence to these mechanisms, which matches research by Ghisellini et al. (2016) and Korhonen et al. (2018). Indeed, it is part of the practitioner appeal of the CE that firms know when they are enacting the CE because its core mechanisms are agreed on (see EMF, 2012, Kirchherr et al., 2017).

Meanwhile, EI has been identified as a key component of harmonizing the twin goals of economic progress and environmental preservation (Kemp, 2010). The concept has been popularized in Europe by non-profit actors and the 'Eco-Innovation Scoreboard' (Eco-IS) ranks EU countries (European Commission, 2021). EIs can take the form of technology, products, processes, or management systems – the qualifying criterion is not the 'how,' but rather that these innovations are aligned to improving the environmental performance of the innovated object to benefit a particular firm and reward efforts (Chen et al., 2006). Similarly, EIs may be developed in any sector by any organization, with the only firm qualifying criterion being environmental benefits over the previous option (Kemp and Oltra, 2011).

Two issues have emerged in the partially overlapping literature on the CE and EI. First, previous research on EI has sought to explain its determinants from several angles, but most progress has been made on the macro-level of regions or nations (e.g. Zeng et al. 2021). While some studies have sought to quantitatively examine the sources of EI performance (e.g. Antonioli et al. 2013), fewer papers have looked beyond an individual organization in this effort (Albort-Morant et al., 2016, Bossle et al., 2016). More empirical work on the sources of EI, particularly work that takes the organizational-boundary spanning mechanisms of the CE into account, is therefore needed.

Second, while the concepts of the CE and EI appear complementary, this is not necessarily so. The concepts approach sustainability with a different impetus: the CE is fairly prescriptive on how sustainability is to be achieved, namely through its mechanisms. Meanwhile, the EI integrates all innovations that are simultaneously economically and environmentally superior, regardless of how environmental superiority is achieved. As such it is unsure what the relationship between the two concepts is. There is an argument that any CE system or technology is an EI in itself, and/or that it is necessary for a firm to be a high-performing eco-innovator to begin implementing anything circular in the first place (Fehrer and Wieland, 2021). Some scholars (e.g. de Jesus and Mendonça, 2018) thus propose that EI precedes the CE from the perspective of a firm, while others argue the opposite (Geissdoerfer et al. 2018). This is a significant question as structuring the increasing wealth of knowledge on both concepts is difficult. More importantly, it is an important question for practitioners because firms must select carefully which sustainability concepts they commit to as their costs are significant and exploiting their potential complementarity should be a priority (Chen et al., 2006, Ghisellini et al., 2016; Tukker, 2015).

To provide empirical evidence on the source of EIs, and solve and explain the conflicted relationship of the two concepts, this study uses path dependence theory. David (1986) describes how path dependences emerge out of system (in)compatibility, economics of scale and quasi-irreversible investments that affect organizations or industries. These factors typically stifle new innovations as the historically grown status quo is entrenched in technology. However, some research shows that path dependence may actually favor innovations if the resources underpinning path dependencies are compatible. In this situation, innovations may benefit from previous path dependencies as existing resources can be creatively recombined (Håkansson and Waluszewski, 2002). This in turn may also lock firms into an innovation path that is pursued in the future (Thrane et al. 2010) because previous innovations have been diffused to a sufficient extent to support the newer innovation in the first place (MacVaugh and Schiavone, 2010). This perspective matches the notion that innovation is often not the result of deliberate and tightly coordinated managerial effort (i.e. 'human push'), but rather emerges from and is driven by multiple sources, for example systems and technologies that are new to the organization (i.e. 'technology push'). Firms struggle to utilize the impetus generated by these sources as the conventional firm-centric model of innovation assumes a linear process originating from management initiatives within firms and aligned with *a priori* strategic objectives (Trischler et al. 2020). Instead, 'technology push' introduces pressure into firms and incentivizes further commitment, creating an unconventional source of innovation by enabling, but also requiring, further complementary action to capitalize on the earlier adoption decision.

Applying this logic to the problem of EI and its sources yields the core proposition that we explore in this paper. Some of the CE systems and technologies are well-known and indeed pre-date the CE terminology. Adoption of such systems and technologies, in this study product take-back and recycling, could be achieved by firms without further environmental commitments. But to integrate and fully capitalize on these systems and technologies, firms make further changes as part of a path dependence, effectively creating complementary innovations (MacVaugh and Schiavone, 2010) or strategic marketing approaches (Schiavone and Simoni, 2019) that form individual steps along this path. This in turn leads to a higher EI performance. Following this proposition, we answer the following questions:

a) What is the impact of adopting CE systems and technologies on EI?

b) How can this impact be explained?

Answering these questions provides empirical evidence on an unconventional source of EI in CE systems and technology induced push, and helps bridge the gap between two of the most influential concepts on business sustainability. We thus fill a blank spot in the application of path dependence in EI research by illuminating a step in the path towards greater EI, while previous work has not considered individual steps. In this process managerial implications emerge, which show that beginning the journey towards a more circular business results in greater EI performance as the firm enacts further changes as it progresses through the path we identify.

The structure of this study is classical. First, a literature review looks at the CE and EI in more detail before building a conceptual model that orders the different concepts of interest. Afterwards, a methodology is designed to test this model and the results of this test are shown subsequently. A discussion connecting the results of this study to the literature follows, and the paper is concluded thereafter.

2. Literature review

2.1. Progress towards a more circular economy

Popularized by Pearce and Turner (1990), the CE is a production and consumption paradigm that attempts to emulate nature's ability to form balanced, cyclical, and closed-loop systems (Andersen, 2007). As it has drawn together different aspects of sustainability research, the CE has 'different meanings and different roles and responsibilities for different stakeholders' (Doranova et al., 2016, p. 9). Conceptually, the CE is founded on industrial ecology, in which usually co-located enterprises form symbiotic relationships by exchanging energy or materials (Murray et al., 2017). Industrial ecology proposes that pollution and waste may become valuable material inputs if manufacturing systems are sufficiently integrated; if this principle is applied to relationships between firms, it 'fosters eco-innovation and long-term cultural change, highlighting the connection between the CE's components and EI (Lombardi and Laybourn, 2012, p. 28). However, the CE has also built on concepts such as cradle-to-cradle and zero waste, as well as other concepts that seek to minimize the damaging or diminishing effect of economic activity on the environment (Ghisellini et al., 2016).

This wider scope argues that the more impactful environmental (and economic) gains are currently untapped as they are embedded in the 'tighter' material flow loops (EMF, 2012). Re-use, repair, and refurbishment and other strategies to preserve value and prolong product lifecycles are expected to overshadow gains made further up the supply chain through industrial ecology and cleaner production, or down the supply chain during disposal (Murray et al., 2017). The research focus has therefore become the *meso*-level of inter-firm collaboration where value generation and capture networks are to evolve around mechanisms that reduce the need for raw material inputs and pollution and waste outputs (Boons and Lüdeke-Freund, 2013). Such closed-loop supply chains rely on re-use, repair, and refurbishment to keep physical goods in circulation as long as possible and reduce the overall environmental burden (see Bocken et al., 2016, EMF, 2012, Stekelorum et al., 2021, Vanany et al., 2021, Xiong et al., 2021). Research shows that firms need to intensify their relationships with up- and downstream partners to move towards such systems as product is to be cycled multiple times to achieve economic and environmental feasibility (Bocken et al., 2016). But the challenges of 'circular supply chain management' are significant. Reverse supply chains with similar sophistication as their corresponding forward supply chains will be required as linear product flows become circular (Geissdoerfer et al., 2018). This stands in contrast to the 'necessary evil' that reverse logistics long has been historically (Genchev et al., 2011, p. 242). Micro-level issues such as adapting existing product and service design processes, firm capabilities, commercialization strategies, and business models interact with the meso-level to impede the CE further (Tukker, 2015). It is therefore unsurprising that successful examples of more radical CE business models are rare and firms prefer gradually adding-on CE systems to their existing business models (Armstrong et al., 2015).

2.2. Eco-innovation

According to Schumpeter (1928), innovation means redeploying productive resources towards new practical uses for economic gain. The full consequences of innovations are unpredictable however; for example, technological progress may become disruptive to established environmental and social systems (Soete, 2013). EI is therefore defined as 'innovation that encompasses or results in environmental damage prevention, mitigation and recovery' (United Nations, 2015).

EI as a concept has begun to consolidate around a number of terms: green innovation (Cuerva et al., 2014), sustainable innovation (Boons and Lüdeke-Freund, 2013), environmental innovation (van den Bergh, Truffer, & Kallis, 2011), and eco-innovation itself (Carrillo-Hermosilla et al., 2010, p. 1075). These terms are used largely synonymously in current research with varying consideration of the social component while the overall focus remains the environment. All concepts attempt to bridge previously separate knowledge silos in engineering, business management, and economics that have occupied with environmental issues for decades. EIs exist on a spectrum from incremental, where existing systems are modified to minimize negative effects of economic activity, to radical, where systems are redesigned to enable positive effects (Carrillo-Hermosilla et al., 2010). An example of the former could be end-of-pipe technologies that seek to prevent pollution resulting from industrial manufacturing. Examples of the latter are rarer, but product sharing systems which replace ownership, or dematerialized services through ICT may be cited (Bocken et al. 2016; Erdmann and Hilty, 2010). Along this spectrum, technologies and processes, business models and supply chains, and ultimately industrial dynamics are innovated by actors (Costantini et al., 2017). Recent findings support the link between EI and financial performance (Xie et al. 2019), making the concept highly relevant to firms.

The diversity of EI is understandably large, and, owing to the previously mentioned knowledge silos, may include technological, social, and institutional innovations (Rennings, 2000) at the level of products, services, processes, marketing, and organization (OECD, 2005). EI include both 'environmentally motivated innovations' as well as 'environmentally beneficial normal innovations' (Carrillo-Hermosilla et al., 2010, p. 1075), and are not dependent on the forerunner idea of Schumpeter's (1928) early work. An EI can therefore be 'imported' into an organization, as the successful application with measurable environmental benefits in comparison to relevant alternatives defines it (Kemp and Pearson, 2008). Alternatively, EIs can also be developed from within an organization when capabilities are leveraged to allow buyers and suppliers to share information and learn from one another (Albort-Morant et al., 2016). The effects of EI on economic and environmental indicators are generally positive but also highly context-specific (Costantini et al., 2017), and numerous internal and external drivers and inhibitors have been proposed over the last years (Bossle et al., 2016, Carrillo-Hermosilla et al., 2010, de Jesus et al., 2017, de Jesus and Mendonça, 2018; Horbach et al., 2012).

2.3. Understanding the relationship between the CE and EI

The relationship between the CE and EI is an uneasy one. At first glance, the concepts seem highly compatible. A focus on economic, environmental, and (to some extent) social sustainability unites them in their goals, but the CE is more prescriptive in how this is to be achieved. While the CE has integrated cleaner production and similar eco-efficiency approaches, the main principle remains loop-narrowing or -closing and circular systems of production and consumption as an antithesis to the status quo (Murray et al., 2017, Su et al., 2013). EI meanwhile embraces all avenues to more sustainability. While radical system re-design to replace existing competencies are encouraged over incremental changes to modify business as usual, circularity is not the favored mechanism on the road to eco-effectiveness, but rather one of many (Carrillo-Hermosilla et al., 2010).

Given this more malleable nature of EI, it is therefore often seen as a catalyst for the CE. De Jesus and Mendonça (2018) for example propose that the increasing clout of the CE concept has made progress at institutional and social level, both through governmental and non-governmental actors. But technological and economic barriers hamper further progress, and this is where EI may provide very tangible solutions towards implementing CE practices in the real world. But there is also the opposite argument. According to scholars such as Geissdoerfer et al. (2018, p. 717), firms commit to circular business models or activities, and then 'push partners and innovation to make their circular business viable. The issue in the current literature is therefore whether CE precedes EI, or EI precedes CE. From the perspective of firms this is an important question because it influences what is considered the relevant entrance barrier to the two most dominant sustainability approaches. Should a firm begin with implementing circular activities, which puts pressure on the firm to ramp up focused EI to make the adopted activities more effective? Or are investments into EI capability necessary to get started with any progress towards the CE in the first place?

This paper argues that the current contradiction can be solved by considering the detail of the CE and its different practices at the firm-level. Looking at how EI and CE intersect, further refinement of industrial ecology may well depend on the development of commercially viable technology and processes (e.g. Yu et al., 2014). This may also be true for radically circular business models that depend on new technologies to disrupt industries (e.g. Chian Tan et al., 2017). But such knowledge does not explain how the two concepts relate to each and here we propose taking the lens of path dependence theory.

2.4. Unconventional path dependences in this relationship

Path dependence theory has mainly influenced economics and political science but has also found application in other fields. The well-known summary of path dependence is that 'history matters,' but this is an oversimplification. While there are numerous contexts in which current events are connected to past events, not all of these contexts exhibit path dependence. Path dependence describes how early (and often arbitrary) decisions or events shape future decisions or events in a stochastic manner (rather than determine them) (Page, 2006). For this reason, the notion of path dependence has been connected to positive feedback loops or increasing returns while switching costs grow simultaneously: 'the probability of further steps along the same path increases with each move down that path [because] the *relative* benefits of the current activity compared with other possible options increase over time' (Pierson, 2000, p. 252). We thus typically observe a range of options for an organization, that gradually narrow down through critical junctures and subsequent lock-in as the path becomes increasingly explicit as more decisions are taken (David, 1986, Sydow et al., 2009).

Several scholars have attempted to make path dependence theory conceptually and methodologically useful for management research (e.g. Garud et al., 2010, Sydow et al., 2009, Vergne & Durand, 2010). Empirical research in this area has looked at firms who build on resources developed earlier to cope with demands encountered later, and traced innovation paths between these resources and demands (e.g. Håkansson and Waluszewski, 2002, Thrane et al., 2010). In research on environmental issues, path dependence has been mentioned but studies usually only consider two factors, which leaves the actual path obscure. Trentin et al. (2015) perform a longitudinal case study and find that the capabilities necessary to deploy mass customization and green management synergize, interpreting their findings using path dependence logic. Meanwhile, Wagner and Llerena (2011) argue that EI are built on capabilities and knowledge that is path dependent and emerge from irreversible historic processes. Horbach (2008) similarly mentions path dependence as previous innovative capability contributes to future EI. Other work implies a path dependence logic but does not expand on it (e.g. Ha, 2021, Sumrin et al., 2021), and overall he existing research EI citing path dependence fails to trace the proposed paths along at least one intervening step between two decisions.

From this perspective, firms initially make choices about their management policies and activities, and then increasingly follow through with complementary (i.e., mutually beneficial and reinforcing) policies and activities that allow them to utilize the resources and knowledge they developed already. For manufacturing and technology firms that have already made the investments necessary to produce and distribute products, we argue that the CE journey is likely to begin with self-commitment to systems and technologies that have environmental but also economic merits, and build on existing capabilities to avoid the costs and risks of a radical transition (Horbach et al., 2012). This is especially relevant given the high cost and risk of more far-ranging innovations (Stefani et al., 2019), such as ones that comprehensively alter business models (Bocken et al., 2016). Among the numerous business models and mechanisms endorsed under the CE label by institutional actors (Murray et al., 2017), take-back and recycling corresponds to the CE mechanism of extending product and resource values so that the need for future production is diminished (Bocken et al., 2016, Tukker, 2015). Such schemes have known economic merits, for example increasing competitiveness through new revenue streams, strengthening customer relationships, and increasing market shares (Eltayeb and Zailani, 2011). Similarly, knowledge on such schemes has been facilitated with consumers and industry since the WEEE directive (Directive 2002/96/EC) and similar regulations, reducing risk and entry barriers and leading to increasing sophistication of these schemes as time has passed and firms have optimized associated systems (Atasu and Van Wassenhove, 2012). However, the investments into such systems remain significant as product design, collection infrastructure, and other resources and skills need to be developed and aligned and even when such systems are developed with economic intent, they are likely to contribute to improving environmental outcomes (Prajapati et al., 2019). This paper therefore takes product take-back and recycling as a proxy for a fairly established and standardized system with associated technologies corresponding to the CE mechanism of product and resource value extension (Bocken et al., 2016), which is in line with recycling being core of CE definitions (Kirchherr et al., 2017). We propose that adoption of this system may serve as an entry point to a path dependence as its adoption likely requires further complementary investment and changes (Sydow et al., 2009).

3. Conceptual framework and hypothesis development

To test our proposition explained in the previous section, this study explores the relationship between CE and EI. In the following, a conceptual framework is developed and subsequently tested using a quantitative methodology. This framework builds on the reviewed literature and argues that engaging in basic CE activities such as take-back and recycling initiatives brings about better EI capabilities directly, as well as indirectly.

3.1. Direct relationship between CE and EI

The CE proposes various mechanisms to improve environmental outcomes. While some of these focus on the production stage, its core proposition are closed-loop business models and supply chains that can result in transformative environmental savings (Murray et al., 2017). If there are no coordinated mechanisms in place to bring products back for repair, refurbishment, and recycling, this is not possible. Driven by regulation such as WEEE directives, changing consumer attitudes, as well as rising raw material prices, firms therefore implement take-back and recycling initiatives, which may be seen as a first step towards a closed-loop supply chains (EMF, 2012, Horbach et al., 2012). We argue that the implementation of take-back and recycling schemes benefits the firm in its EI capability. This is because take-back and recycling initiatives would do little to contribute to firm's competitiveness when combined with orthodox management, product design, or operations and marketing approaches (Tukker, 2015). Committing to such initiatives therefore acts as a push-factor to pursue EI further to integrate the initiatives successfully. This argument is in line with studies showing that the adoption of environmental initiatives causes the adoption of other environmentally-focused concepts to improve total outcomes and form a coherent whole (e.g. Darnall et al., 2008, Zhu et al., 2010). Accordingly, we hypothesize that:

H1: Take-back and recycling initiatives have a positive impact on eco-innovation.

3.2. Exploring the bridges between the CE and EI

Research shows that take-back and recycling initiatives cannot be implemented by a firm in isolation (Tukker, 2015). Changes across the supply chain are necessary to support the implementation of CE activities and capitalize on efforts initiated by firms facing the end-customer to achieve envisioned economic and environmental gains (Geissdoerfer et al., 2018). The implementation of reverse logistics systems, a requirement for take-back and recycling initiatives, results in closer collaboration with suppliers to adapt product design for reverse logistics, which in turn incentivizes adoption of green supply chain management practices (Diabat and Govindan, 2011). Indeed, it appears that firms are more likely to see economic as well as environmental success from CE activities if they also adopt environmental-oriented supply chain management approaches as the integration of up- and downstream partners is critical to set up efficient processes and infrastructure (Zhu et al., 2010). We therefore argue that firms which adopt take-back and recycling initiatives are also more likely to adopt environmental management policies across their supply chains:

H2: Take-back and recycling initiatives have a positive impact on environmental supply chain policies.

Measuring, managing, and improving environmental performance across supply chains requires coordination and collaboration on a variety of activities, for example, reducing packaging and waste, developing eco-friendly products, or reducing environmental effects from transportation (Walker et al., 2008). Deeper integration facilitates the conditions necessary for EI to emerge through joint interaction as firms realize economic and environmental synergies (Mylan et al., 2015) and (Albort-Morant et al., 2016) show that buyer and supplier relationships focused on learning and information sharing contribute to EI. Environmentally-minded collaboration, such as through green or environmental supply chain management, is therefore strongly linked to the development and diffusion of EI (Costantini et al., 2017; Sarkis et al., 2011, Seman et al., 2019), particularly when they concern products innovations (Horbach et al., 2012). We therefore propose that:

H3: Environmental supply chain policies have a positive impact on eco-innovation.

When a firm implements take-back and recycling initiatives, measuring and managing their performance is important for legitimizing the initiative and inform its functioning (Chen et al., 2019). Neither financial feasibility nor environmental superiority of such schemes is assured by default, and previous studies have yielded inconclusive results (Tukker, 2015). Environmental management systems (EMS), such as the ISO 14001 standard, define requirements that firms have to comply with to improve their environmental performance. These requirements involve monitoring and measurement of environmentally relevant operations, as well as ensuring compliance with regulations, among others. The adoption of an EMS is seen as an organizational level EI with significant effects on a firm's operations (Horbach et al., 2012). We argue that take-back and recycling initiatives encourage adoption of EMS since it gives firms the structure and tools to gather and utilize data from their processes. Internally, such data can be used to optimize the take-back and recycling scheme, while externally the data can be used to foster a green brand with consumers or demonstrate environmental commitment to regulators (Darnall et al., 2008). We therefore hypothesize that:

H4: Take-back and recycling initiatives have a positive impact on the adoption of environmental management systems.

Early studies to validate the link between EMS and EI have been inconclusive. In some instances, no significant effect was found (Frondel et al., 2008), whereas in others EMS may indeed foster certain types of EI, namely process- but not product-related innovations (Wagner, 2008). More recent results however argue that EMS adoption is in itself an organizational EI that may benefit future EI capability, if adopted for the right reasons. When adopted voluntarily to imitate successful competitors or due to gradually increasing professional standards in an industry as knowledge is disseminated, EMS may lead to innovation, whereas coercive motivation through regulation does not result in this relationship (Daddi et al., 2016). Other studies (Cuerva et al., 2014, Hernandez-Vivanco et al., 2018) also argue that voluntary adoption of or integration of management systems contributes to EI. Overall, 'environmental management systems (EMS 2006) are significantly important for EIs' as they equip organizations with information gathering and interpretation capabilities to recognize and push for a wide range of EIs (Horbach et al., 2012). We therefore hypothesize that:

H5: Environmental management systems have a positive impact on eco-innovation.

With circularity in material flow relationships between members of a supply chain, the information gathering and sharing requirements increase (Mangla et al., 2021, Zhan et al., 2021). Take-back and recycling initiatives result in closer relationships between manufacturers and customers as the frequency and nature of interaction changes. To facilitate the efficient planning and management of such schemes, firms are incentivized to collect information on the location, use, and likely return condition and time of the product (Ardolino et al., 2018). This may be simulated based on aggregated data to inform the design of take-back and recycling initiatives, but firms also want to stay in contact with customers directly, particularly when the initiatives are part of integrated service offerings. Given that such initiatives are often managed together with third parties and/or through continuous electronic data exchanges, privacy concerns are high and a distinct barrier to closer relationships (Suppatvech et al., 2019). While this data is precious to the customer, it also enables the take-back and recycling initiative itself, and becomes a source of competitiveness. Firms therefore have a strong incentive to keep such data secure across the supply chain, leading us to the hypothesis that:

H6: Take-back and recycling initiatives have a positive impact on data protection policies.

One of the determinants of EI has been summarized as 'technology push' as knowledge capital fosters innovative capability (Bossle et al., 2016, Horbach et al., 2012). Cañón-de-Francia et al. (2007) find that firms with greater technological knowledge are able to lessen the business impact of more stringent environmental regulation by harnessing their innovativeness to develop efficient solutions. Gupta et al. (2020) similarly find that investments into technology enable future EIs in the supply chain domain. We therefore hypothesize that the necessity to implement data protection policies due to the implementation of take-back and recycling initiatives positively affects EI as technology and ICT capabilities in particular are upgraded:

H7: Data protection policies have a positive impact on eco-innovation.

Lastly, we hypothesize that the three previously displayed policies mediate the relationships between CE and EI:

H8: Environmental supply chain policies mediate the relationship between take-back and recycling initiatives and eco-innovation.

H9: Environmental management systems mediate the relationship between take-back and recycling initiatives and eco-innovation.

H10: Data protection policies mediate the relationship between take-back and recycling initiatives and eco-innovation.

Taking these hypotheses together, Figure 1 below summarizes our argument. Take-back and recycling initiatives as a first, cautious step into CE practice benefit EI directly, as well as indirectly through complementary upgrades, which in turn further improve EI.

<Insert Figure 1 about here>

4. Methodology

4.1. Data and research setting

We collected data from the Thomson Reuters ASSET4 database, consisting of 11 years of data from 2009 to 2019 on Environmental, Social and Governance (ESG). This database comprises more than 11,000 firms across 138 sub-industries. The compilation includes publicly available information, covering annual reports, sustainability issues and proxy filings with news (Reuters, 2011). The unit of analysis is the firm subjected to EI monitoring. Our research analyses 724 firms across 33 countries and 11 industries, which are predominantly in the manufacturing and technology sector. These firms are selected based on having been involved in EI activity within the past decade and possess a relatively stable market share across the period of observation. Table 1 summarizes the model variables and the related operational definitions.

<Insert Table 1 about here>

4.2. Method

This study uses the seemingly unrelated regression (SUR) method for testing the three mediators (*Escp, Ems, Dpp*) on the relationship between take-back and recycling initiatives (*Take_back*) and EI (*Eco_Inn*). The term 'seemingly unrelated' indicates that although the system of regression equations may appear unrelated, they appear so because their errors are correlated (Zellner, 1962). This is an appropriate test of our research model since SUR simultaneously assesses and compares the mediating effects of our three mediators.

Our SUR model consists of four multiple regression equations as follows:

Our SUR model consists of 4 multiple regression equations as follows:

Model 1: $Escp = \beta_1 Take\_back_1 + \gamma_1 Turnover + u_1$

Model 2: $Ems = \beta_2 Take\_back + \gamma_2 Turnover + u_2$

Model 3: $Dpp = \beta_3 Take\_back + \gamma_3 Turnover + u_3$

Model 4: $Eco\_Inn = \beta_4 Escp + \beta_5 Ems + \beta_6 Dpp + \beta_7 Take\_back + \gamma_4 Turnover + u_4$

Note that the U vector is homoscedastic, thus it comprises of the expected error variance $E(u_1^2) \neq E(u_2^2) \neq E(u_3^2) = E(u_4^2)$. Hence, it is not simply the case of running separate ordinary least squares for each of the equations.

5. Results

Correlations and descriptive statistics are provided in Table 2. We find that environmental supply chain policies, data protection policies, and take-back and recycling initiatives are positively correlated with EI, while environmental management systems and inventory turnover are not. Other than EI and data protection policies, inventory turnover as the control variable is correlated with the remaining variables. With regards to the three mediators, only the relationship of environmental management systems and environmental supply chain policy is not correlated.

<Insert Table 2 about here>

Table 3 shows the main direct effects of take-back and recycling initiative on the mediator variables (i.e. environmental supply chain policy, environmental management systems and data protection policy) and outcome variables (i.e. EI) using SUR models, while inventory turnover is the covariate. First, we examined whether take-back and recycling initiatives have a significant impact on the mediators by comparing Model 1, Model 2 and Model 3. The results show that increasing take-back and recycling initiatives have a greater effect on environmental supply chain policy and data protection policy, but not on environmental management systems.

Next, we investigate the direct relationship between take-back and recycling initiatives and EI. The results in Model 4 revealed that apart from the significant impact of increasing recycling and take-back initiatives on EI, environmental supply chain policy has an impact as well while controlling for inventory turnover.

<Insert Table 3 about here>

The mediating effects are further investigated for the relationship between take-back and recycling initiatives and EI. The significance of the indirect effects is tested using the asymptotic and resampling strategies of Preacher and Hayes (2008) on 5,000 samples. In our study, we use the bias-corrected bootstrap confidence intervals for the interpretation of the significance of the indirect effects. The mediation results showed that only its indirect effect through environmental supply chain policy ($b = 0.585$, $p < 0.01$) is significant while data protection policy ($b = 0.009$, p = n.s.) and environmental management systems ($b = -0.049$, p = n.s.) do not mediate said relationship. Table 4 summarizes the results of the hypotheses, which are visualized in Figure 2.

<Insert Table 4 about here>

<Insert Figure 2 about here>

6. Discussion

The first result confirms that adoption of CE systems and policies, in this case represented by take-back and recycling initiatives, contribute to EI. This result gives a contribution to the knowledge on the CE as well as innovation for different reasons. Firstly, this result are aligned with previous studies suggesting that the commitment to take-back and recycling initiatives and other CE-aligned policies act as a push-factor to build EI capabilities (Geissdoerfer et al., 2018), which answers the call of studies on EI sources and diffusion (Albort-Morant et al., 2016, Xie et al., 2019) for more quantitative and robust evidence on this type of relationship.

Indeed, to the best knowledge of the authors, this is the first quantitative study that considers the development of take-back and recycling initiatives and environmental innovation scores, with a cross national and cross sectorial sample of this size. A key assumption behind these conclusions is that a longer adoption of take-back and recycling initiatives as well as subsequent EI performance gains corresponds to the achievement of more sophistication over time. This assumption is based on the idea of a positive learning curve following the implementation of take-back and recycling initiatives as well as innovation, backed by previous empirical studies (Horbach et al., 2012), as well as the notion that innovations do not immediately pay off on their own and that innovation projects should be evaluated within the strategy that accompanies the project (Stefani et al. 2019). As firms adopt individual CE systems, they implement further environmentally-minded policies to exploit these and this further benefits the development of EI in the future.

The second result of the study is that environmental supply chain policies mediate the relationship between CE and EI, which is in line with what can be glimpsed from previous research (Sarkis et al., 2011, Zhu et al., 2010). This highlights that the adoption of CE-related activities has environmentally beneficial effects on organizational priorities beyond the immediate firm that implements them and ties in with research on how firms need to support the diffusion of innovations by communicating and coordinating with external stakeholders beyond the innovation itself (Schiavone and Simoni, 2019). Such complementarity has been observed previously in different contexts (MacVaugh and Schiavone, 2010, Thrane et al., 2010) but our results illustrate a path that is traced through sustainability-oriented action towards EI performance over time.

However, nothing can be said on the mediating role of environmental management systems or data protection policies. In terms of contribution to knowledge, this result does not imply that environmental management systems or data protection policies do not have a positive impact on the EI performance of the firm. The relevance of environmental management systems or data protection policies has been widely proven in the scientific literature (e.g. Daddi et al., 2016, Horbach et al., 2012) and we do not argue that our results invalidate this literature. However, our two variables measure the number of years for which the firm has environmental supply chain policies, environmental management systems, or data protection policies in place. As such our results rather indicate that the benefits of environmental management systems and data protection policies on EI are more time-sensitive than for environmental supply chain policies. Firms might see the benefits of environmental management systems or data protection policies soon after their implementation, without having to achieve higher levels of development comparable to the ones of environmental supply chain policies. The result can be explained considering the complexity of environmental supply chain policies compared to the other mentioned practices. This means that while environmental supply chain policies are an important mediator between the CE and EI, environmental management systems and data protection policies might have more immediate benefits and require less time to reflect positively in EI performance.

Discussing our results using the terminology and logic of path dependence theory allows us to contribute to solving the conflicted relationship between the CE and EI. We propose that our study indicates an emerging path dependence with established CE systems such as product take-back and recycling as an entry-point, and environmental supply chain policies as a further step down the same path because firms attempt to increase the returns of the CE system (see Pierson, 2000). This conceptualization of the innovation in the environmental context of the CE and EI differs from research implying that innovation is driven by deliberate planning of management (e.g. Trischler et al., 2020) and is more akin to the notion of 'technology push' discussed by Bossle et al., 2016, Horbach, 2008, and Horbach et al. (2012).

Our research thus chimes with research by Trentin et al. (2015) and Wagner and Llerena (2011): as firms develop complementary capabilities implementing CE systems and policies, they become increasingly locked-in as the relative benefits of utilizing and further developing these capabilities increase over the alternative of abandoning them or backtracking. From this perspective, comparatively enhanced EI performance is likely not the ultimate end-point of this path, but rather a further step towards an increasingly committed environmentally conscious future for the relevant firms. For example, Seman et al. (2019) find that green innovation mediates the relationship between green supply chain management policies and overall environmental performance. Thinking this further, the more comprehensively circular business models envisioned by Bocken et al. (2016) may well follow on from improved EI performance as de Jesus and Mendonça (2018) suggest and result in a reinforcing loop towards overall improved environmental performance. Path dependence theory thus allows us to integrate both perspectives on the CE and EI by conceptualizing them as part of the same path and seeing them as mutually reinforcing with complementary policies and systems in-between, but that this path is likely to start from the CE as it is more prescriptive in its practice than EI.

7. Conclusion

7.1. Summary and contribution

Research on innovations that simultaneously contribute to economic and environmental goals has progressed to identify sources contributing to innovation capability of firms. But firms struggle to achieve such innovation for a variety of reasons, not least the investment necessary. Furthermore, it is unclear where firms are to start with the relationship with two of the most well-known concepts, CE and EI, being conflicted. Some researchers see circular policies and the systems and technologies they entail as the result of EI while others propose that some progress towards implementing circular policies can spur further EI activity. In this paper, we thus answer two questions: a) What is the impact of adopting CE systems on EI, b) How can this impact be explained?

Concerning the first question, our results show that a firm's EI capability will benefit from adopting CE systems such as product take-back and recycling. Concerning the second question, the adoption of such systems and associated technologies can have a direct and beneficial effect on future EI as firms implement environmental supply chain management policies to further capitalize on these systems, which further benefits EI.

Our paper contributes to literature in two ways. Firstly, our empirical results show the complementarity between different concepts that have been researched and discussed previously from different angles. The finding that environmental supply chain policies act as a mediator between the CE and EI allows us to connect three bodies of literature that researchers have struggled to empirically link in research despite their strong conceptual and logical overlap. Based on our results we propose that the CE and EI meet at the level of the supply chain and that coordination across supply chains acts as a bridge that allows firms to capitalize on the adoption of CE systems with their partners. This notion is also strengthened as neither environmental management systems adoption or data protection policies act as mediators.

Our second contribution comes from the application of path dependence theory, which allows us to further interpret our results and enrich research on the sources of EI (e.g. Bossle et al., 2016, Xie et al., 2019) and the effects of the increasingly commonplace applications of the CE principles in industry (e.g. Chen et al., 2019, Fehrer and Wieland, 2021). Using path dependence as a lens allows us to order the CE and EI concepts logically in the same model and resolve the contested relationship of the two (Geissdoerfer et al., 2018, de Jesus and Mendonça, 2018) and identify an unconventional source of EI: CE induced path dependence.

The adoption of CE systems and technologies acts as a starting point of a path and drives future decisions in a firm through positive feedback loops, which ultimately result in EI not as 'human management push' but rather 'technology push' necessitated by the earlier adoption decision. This supports Wagner and Llerena's (2011) and Horbach's (2008) works but expands on them by eliciting a complementary step in this path in environmental supply chain policies. The adoption of CE systems and technologies can thus escalate future commitment. Further progression down this path may well include further commitments towards the implementing circular flows of products such as more radical CE business models, although we do not confirm this empirically.

We propose that this lens can help understand sustainability activities by firms as it allows researchers to test sequential relationships between different concepts but simultaneously acknowledge that they may reinforce each other as part of a broader environmentalist firm path. This is especially vital as the bodies of literature on the CE, EI, environmental supply chain management, and other concepts have branched out, making consolidation work more vital than ever. Seeing the CE and EI as reinforcing (with complementary policies such as environmental supply chain management in-between) can thus help research understand how environmentally-minded innovations can be motivated by previous, seemingly unrelated system and technology decisions.

7.2. Managerial implications

Practitioners can use the results of this study in different ways. Firstly, the study suggests different pay-off horizons for the implementation of environmental supply chain policies, environmental management systems, or data protection policies. Guidelines related to the implementation of environmental supply chain policies should highlight that it can take several years until they show their positive impact in terms of EI. Therefore, the first years of CE-related systems need to be overcome before environmental supply chain policies and innovation can evolve in a synergistic way to bring them to more economic and environmental success. More fundamentally, our results show that a firm wishing to improve its EI performance can do so by deliberately pushing it down this path of environmentally sustainable action via adoption of a fairly well-known and specific CE policy: product take-back and recycling systems and their associated technologies.

The results of this study may also aid governmental and non-governmental actors in the sustainability area. That environmental supply chain policies mediate take-back and recycling initiatives and EI strengthens the argument for gradually fostering commitment to the CE among individual firms which then results in positive spillovers later. Our results therefore confirm that quickly moving from a linear to a circular business model (see Bocken et al. 2016) is unnecessary. Our results highlight that even the more modest CE activities that do not result in radically new business models build innovative capabilities over time, which might remain a stronger driver for profit-oriented firms than the initial environmental gains of the product take-back and recycling itself. Even if initial improvements in EI capability are aimed to increase the viability of product take-back and recycling adopted earlier, we propose that such capability could be redeployed towards other ends at a later date. As such, firms build a flexible competitive advantage in the long-term as environmental regulations and consumer expectations tighten and EI becomes more important. Our results can thus help thinktanks, such as the Ellen MacArthur Foundation, convince firms of progressing towards the CE as our results provide a convincing logic and argument in support of gradual commitments to let firms experience the benefits of individual activities.

7.3. Study limitations and future research directions

The study has several limitations and we identify two major future research directions based on them. Firstly, there are several other variables that could be used to control the relationship between environmental supply chain policies, environmental management systems, or data protection policies. These variables include the country, the general performance of the firm, the industrial sector, the managerial models in place in the specific firm, and so on. Therefore, further research can include these variables to consolidate and refine the results of the study. Secondly, the mediating variables are to some extent self-reported by the firms of the sample. Although this is a very good proxy of the actual implementation of the related practices, previous studies observed that the firm's claims could be biased, and managers could overestimate their capability of implementing environment management practices (e.g. Guedes and Gonçalves, 2019). Therefore, future research can explore the same relationship by adopting more objective measures of the mediating variables.

We also propose three further future research directions that emerge from the results of our study. The first of these is tied to the policies or technologies that can trigger the path dependence we identify in the case of take-back and recycling. Such systems and associated technologies are one of the most established core principles underpinning the CE in Europe and North America. But elsewhere other systems are more strongly associated to the CE, such as industrial ecology and symbiosis in China (Ghisellini et al. 2016). To what extent can a firm's participation in industrial symbiosis relationships trigger comparable path dependencies and what paths could emerge from this decision? Our utilization of path dependence theory opens up a fruitful new avenue that allows other researchers to trace the multiple connections between disparate environmental concepts, and we propose that industrial ecology or the use of recycled feed materials in manufacturing processes are prime candidates for exploring this avenue further.

The second research direction homes in on the role of environmental supply chain policies, which we show mediates the relationship between product take-back and recycling and EI. We explain the reason for this mediation above, but there may be other circumstances that influence its existence and we propose that moderated mediation models may explore these circumstances further. For example, the size of the firm or exact nature of the product to which the take-back and recycling apply may influence whether a firm sees environmental supply chain policies as necessary. Further research could specify the exact path that firm takes from the adoption of such systems to an increase in EI and the major forks involved in that path.

The last research direction emerges from our application of path dependence theory and our interpretation of the potentially reinforcing dynamic between the CE and EI. Imagining a firm which has implemented a relatively straightforward CE system like product take-back and recycling and subsequently seen an improvement in EI performance – what is next? We would expect to see a further commitment to another environmental concept that capitalizes on the previously developed capabilities. Bocken et al. (2016) and Tukker (2015) give insights into CE-related business models that fit this description. We would recommend future research to trace the path we have explored in this paper further, for example through a longitudinal case study. Such a study could further disprove or support our interpretation of our results here and allow researchers to better structure different environmental concepts in relation to each other.

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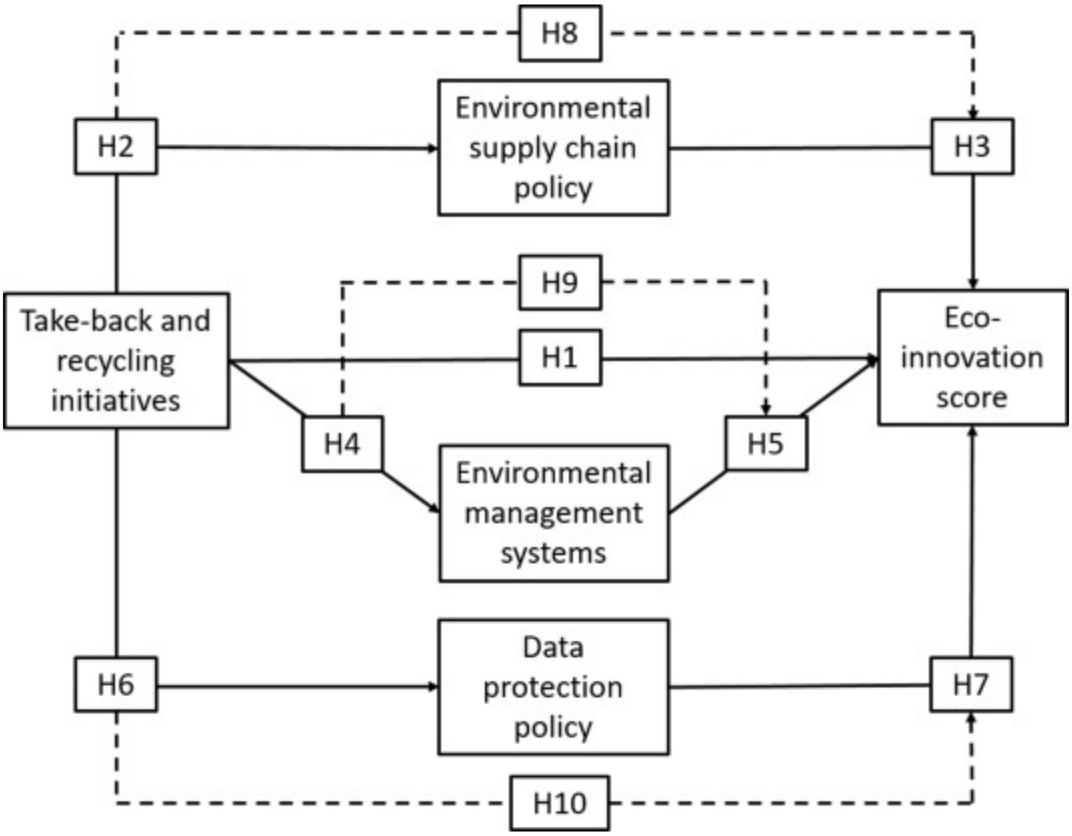

Figure 1: Hypothesized structural model.

Table 1: Model variables and operational definitions.

Variable	Type	Operational Definition
Eco-Innovation (Eco_Inn)	Dependent	This is a score reflecting a firm's capacity to reduce its own environmental costs and burdens for its customers in relation to new market opportunities derived from new environmental technologies and processes or eco-designed products.
Take-back and recycling initiatives (Take_back)	Independent	The number of years that the firm has reported practicing take-back procedures and recycling programs which reflect the product and resource value extending mechanisms of the CE (Bocken et al., 2016).
Environmental supply chain policy (Escp)	Mediator	This is a sum of three variables on supplier integrity, composed of selection of suppliers based on environmental standards, willingness to end a non-compliant supplier's relationship, and the practice of continuous environmental monitoring of its supplier (Mylan et al., 2015).
Environmental management systems (Ems)	Mediator	The proportion of firm sites or subsidiaries in compliance with environmental management system certification (in percentage).
Data protection policy (Dpp)	Mediator	Number of years that the firm has a data privacy policy in place to safeguard customers' confidential data.
Inventory Turnover (Turnover)	Control	This is a proxy for firm size (Gaur and Kesavan, 2015) that may influence a firm's environmental costs and burdens, but also the resources needed for exploiting new market opportunities using environmental technologies and processes or eco-designed products.

Table 2: Correlations and descriptive statistics.

Variables	***Eco_Inn***	***Escp***	***Ems***	***Dpp***	***Take_back***	***Turnover***
Eco_Inn	54.89(26.43)					
Escp	0.240***	12.76(9.46)				
Ems	−0.008	−0.018	74.92(30.06)			
Dpp	0.115***	0.476***	−0.085**	5.40(3.96)		
Take_back	0.228***	0.434***	−0.046	0.318***	1.95(3.64)	
Turnover	0.044	−0.095**	0.061*	−0.055	−0.085**	15.08(47.09)

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, Mean (Std. Dev.) in diagonals.

Table 3: Seemingly Unrelated Regression model results.

	Model 1	**Model 2**	**Model 3**	**Model 4**
	Escp	*Ems*	*Dpp*	*Eco_Inn*
Turnover	−0.012*	0.037	−0.002	0.042**
	(0.007)	(0.024)	(0.003)	(0.020)
Take_back	1.114***	−0.342	0.343***	1.155***
	(0.087)	(0.307)	(0.038)	(0.290)
Escp	–	–	–	0.525***
	–	–	–	(0.121)
Ems	–	–	–	−0.003
	–	–	–	(0.032)
Dpp	–	–	–	−0.144
	–	–	–	(0.274)
Constant	10.773***	75.025***	4.774***	46.287***
	(0.376)	(1.327)	(0.166)	(3.028)
Chi^2	171.83***	3.98	82.05***	64.77***
Obs.	724	724	724	724
R^2	0.192	0.01	0.102	0.082

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors are in parentheses

Table 4: Results of hypotheses testing.

Hypotheses		
H1	Take-back and recycling initiatives contribute to the eco-innovation.	Supported
H2	Take-back and recycling initiatives contributes to environmental supply chain policies.	Supported
H3	Environmental supply chain policies contribute to the eco-innovation.	Supported
H4	Take-back and recycling initiatives contribute to environmental management systems.	n.s.
H5	Environmental management systems contribute to eco-innovation.	n.s.
H6	Take-back and recycling initiatives contribute to data protection policies.	Supported
H7	Data protection policies contribute to eco-innovation.	n.s.
H8	Environmental supply chain policies mediate the relationship between take-back and recycling initiatives and eco-innovation.	Supported
H9	Environmental management systems mediate the relationship between take-back and recycling initiatives and eco-innovation.	n.s.
H10	Data protection policies mediate the relationship between take-back and recycling initiatives and eco-innovation.	n.s.

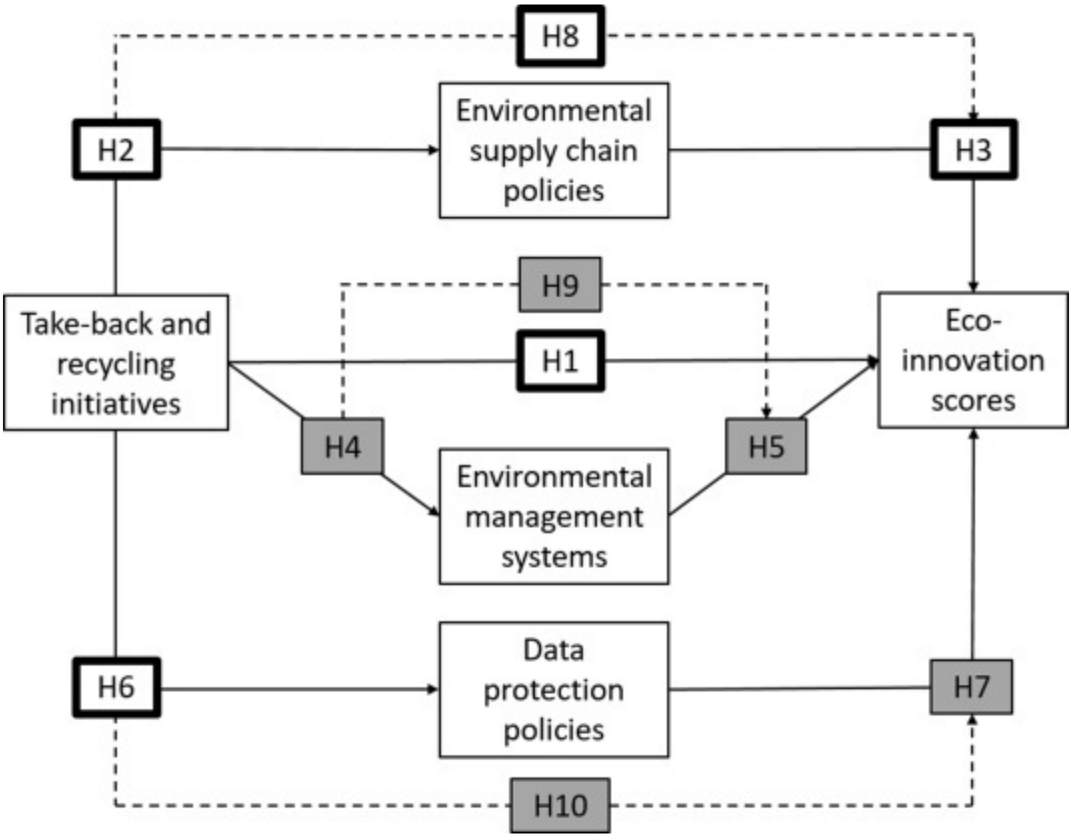

Figure 2: Results (bold black outline denotes confirmed hypotheses, while grey shading denotes rejected hypotheses).