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CIRCULAR ECONOMY PRACTICES AND INNOVATIVE BEHAVIORS. LESSONS FROM EMPIRICAL RESEARCH IN THE CHEMICAL INDUSTRY

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Abstract: The circular economy is gaining momentum as a viable alternative to the linear economic model. However, little is still known about the factors that motivate companies to adopt circular economy practices. In this paper, we contribute to the literature by showing that there is a link between the innovative behavior of firms and their investment in circular economy practices. We draw on the results of a survey conducted in 2020 among a thousand companies in the chemical sector. Estimates from Probit models clearly show that companies that carry out environmental or frugal innovations, or simultaneously innovate in products and processes, are more likely to carry out circular economy actions. Analytical and public policy implications are drawn from these results.

Keywords: Circular economy, environmental innovation, frugal innovation, complex innovator.
JEL code: L1, O31, O33, Q2

Résumé : L'économie circulaire se développe fortement en tant qu'alternative viable au modèle économique linéaire. Cependant, on sait encore peu sur les facteurs qui motivent les entreprises à adopter des pratiques d'économie circulaire. Dans cet article, nous contribuons à la littérature en montrant qu'il existe un lien entre les comportements innovants des entreprises et leur investissement dans les pratiques d'économie circulaire. Nous nous appuyons sur les résultats d'une enquête menée en 2020 auprès d'un millier d'entreprises du secteur de la chimie. Les estimations des modèles Probit montrent clairement que les entreprises qui réalisent des innovations environnementales ou frugales, ou qui innovent simultanément dans les produits et les processus, sont plus susceptibles de mener des actions d'économie circulaire. On tire des implications analytiques et de politiques publiques de ces résultats.

INTRODUCTION

The circular economy (henceforth CE) is developing strongly within different sectors of activity and is increasingly recognized by economic agents and public decision-makers (Kirchherr et al., 2017; Niang et al., 2020). With the emergence of the CE, the linear economy model is being abandoned to build a circular systemic relationship. It is defined by Geissdoerfer et al. (2017)

as follows: 'the CE is a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling'. This definition is in fact very operational. It highlights an 'engineering approach' with many advantages for analyzing material, energy and resource flows (Gallaud and Laperche, 2016). Korhonen et al. (2018) bring a complementary vision by proposing that: 'circular economy is an economy constructed from societal production-consumption systems that maximizes the service produced from the linear nature-society-nature material and energy throughput flow. This is done by using cyclical materials flows, renewable energy sources and cascading type energy flows' (p. 39). This definition shifts the CE from a technical systems issue to one related to production ecosystems.

From these definitions, it can be seen that the CE represents a new paradigm (de Jesus et al., 2018) and that the transition from linear to circular economies implies significant changes. In fact, the CE requires fundamental transformations in production and consumption patterns (Korhonen et al., 2018). The impacts of circularity on resource, material and energy flows are numerous (de Jesus et al., 2018), including minimization of inputs and efficient use of regenerative resources, efficiency of energy processes, focus on renewable and non-hazardous materials, life extension and redesign of systems, and output reduction, recovery and waste minimization. The transition toward the CE represents a radical change in the way material and energy flows and interactions between companies are managed. In short, engaging in CE practices is not simple, companies face many obstacles and must build appropriate procedures to succeed.

In this context, a significant stream of research on the determinants and barriers to the CE transition has emerged. A quick review of this literature shows that, although the relationship between CE and innovation is perceived as important, this issue remains unexplored. Innovation is identified as a means of driving the transition to circular forms of production and consumption, and it is important to tease out the exact relationship between them. In order to contribute to this debate, we try to understand why and how innovation and CE interrelate to each other. The objective is to identify whether and how firms' innovation behaviors prepare and motivate them to undertake CE-related changes. In other words, we join the discussion related to the determinants of CE practices, but our focus is innovation.

Our article is organized as follows: the first section deals with the determinants of CE through a review of the literature, which contextualizes and justifies our research question. The second section discusses the analytical framework of our study and the hypotheses that we propose to test. The survey and data are described in Section 3. The final section presents our econometric analysis, the estimated models, and our results. In conclusion, we review our results and discuss the different implications of our research.

1. DETERMINANTS OF THE CIRCULAR ECONOMY: LITERATURE REVIEW AND RESEARCH QUESTION

We distinguish three categories of determinants of the CE: regulations compliance, demand pull and supply push factors.

The first category of determinants is regulatory. It has been argued that the development of the CE is viable only if the government provides adequate promotion of, and support for, R&D, education and training, in order to increase awareness and create the required skill base necessary for the CE (Gao et al., 2006; Geng et al., 2010). The CE also requires 'dedicated public policies and new forms of cooperation between enterprises and public actors' (IAU, 2013, p. 16). Legislative and regulatory framing of the CE, including taxes, incentives, infrastructure development, has been widely considered as a leading factor in promoting an institutional framework conducive for the CE. Indeed, the EU 2015 Action plan for the CE 'establishes a concrete and ambitious program of action, with measures covering the whole cycle: from production and consumption to waste management and the market for secondary raw materials', covering not only legislative efforts but also funding tools (EC, 2015, p. 2). In addition, the government can act in favor of reliable labels that respect CE principles as well as release public orders to guide consumption (Aurez and Georgeault, 2016). Such efforts are helpful in addressing the lack of 'smart regulation' (Preston, 2012, p.16) and 'supportive policy frameworks' (Rizos et al., 2015, p.1) for a transition towards a CE.

The second category of determinants relates to demand. The market is characterized by a growing trend towards green consumption (OECD, 2008), which motivates companies to be more sustainably oriented. New products serving a CE (such as energy saving products or products characterized by a better recyclability or a longer lifetime) may lead to first mover advantages that are accompanied by a higher competitiveness of the innovating firm (Porter & van der Linde, 1995). The need to improve resource performance and reduce the costs of material input, resulting from the current level of resource consumption and the problem of resource depletion and volatility, also prompts economic actors to be more open to the circular mode of production (Geng et al., 2014). Besides, social and cultural factors deserve attention in the transition to the CE. They characterize general social trends, including social sensitivity to environmental problems, shifting customer preferences to a responsible mode of consumption, perception toward sustainable resource consumption, and business perception of reputational gain by undertaking sustainable measures (Ranta et al., 2018). For example, customers' desire for 'product service systems', 'performance-based contracting', 'product as a service', and 'servitization', which are circular business models, is an important driver of the CE (de Jesus and Mendonça, 2018). The perception towards the value of waste management and resource recycling can motivate companies to be more circular in their activities (Ranta et al., 2018). However, the concept of CE has not become mainstream since it 'has not been widely integrated in the strategy, mission, vision, goals & key performance indicators' of companies (Pheifer, 2017, p.10).

The third category of determinants is supply factors. Technical factors are fundamental in the transition towards the CE. The availability of technical solutions is an essential condition for ensuring product durability, efficiency, as well as quality. They are necessary for the design of optimal product life-cycle scenarios and production processes. Therefore, one technically-related determinant of the CE involves the existence of appropriate technologies (Yu et al., 2014), which have reached the appropriate technological thresholds for circular operation (de Jesus and Mendonça, 2018). Another is the availability of sufficiently specialized personnel, who can make the best use of these technologies in CE processes (Gao et al., 2006). Without competent staff, there will be a problem that has been termed technology gaps (de Jesus and Mendonça, 2018), such as the lag between technological development and its application in production (Vernay et al., 2013). Finance is also an important aspect from the supply side. Companies are deterred from engaging in CE processes by high initial investment costs and market uncertainty (Matus et al., 2012). It is difficult for them to move away from the lock-ins created by path-dependencies created by the prevailing socio-technical systems of the linear economy (Markard et al., 2012). For example, the low prices of many virgin materials would prevent CE products from outcompeting their linear equivalents (Mont et al., 2017) and the recycling of many materials is difficult because it is uneconomic relative to the production of virgin material (Preston, 2012).

Based on these theoretical insights, it can be seen that the literature has not largely explored the idea that innovation implemented by firms should be a precondition of their engagement in CE processes (see Vence and Pereira (2019) for an exception). Innovation in itself can encourage CE practices. The transition to the CE is a process of reconfiguration and adaptation that

requires intensive innovations (de Jesus and Mendonça, 2018). It is largely influenced by the adoption, production and diffusion of innovations internal to firms (Cainelli et al., 2020). As the role of knowledge assets and human resource management is important in explaining the performance of firms in the environmental field at large (Antonioli et al., 2013; Galliano and Nadel, 2013), it can be argued that an innovative firm has sufficient technical skills to successfully implement new technological processes related to circularity (even if this is done with other actors). Innovative firms also have the economic skills that enable them to make adequate research, investment and market intervention choices (Carlsson and Eliasson, 1994).
The argument that an innovative firm is better positioned to implement CE processes is developed in the following section on the research framework.

2. CONCEPTUAL FOUNDATION AND HYPOTHESES

Our central argument is that innovative behaviors of firms drive their engagement in CE practices. We undertake an in-depth investigation of this relationship by testing the impact of different innovative behaviors on the propensity to implement CE processes. It is therefore important to clearly define the types of innovation we examine.
A technological innovation is a new combination of existing ideas or recombined or updated pieces of knowledge (Fagerberg, 2005, p. 10), resulting in a viable and cost-effective solution (Tidd, 2006). When looking at the nature of innovation, a distinction is made between product technology innovation and process technology innovation (Fagerberg, 2005). The former corresponds to the creation of a new or improved product, whereas the latter involves changes in the way a product is made (manufactured) without changing its structure (Swann, 2009). Fagerberg (2005) points out that product innovation has a real positive effect on growth and employment. Process innovation strategies are associated with the search for better price competitiveness, while product innovation strategies are more related to the search for technological leadership (Pianta, 2005).
A richer typology in terms of dynamic implications has been introduced by the research of Le Bas and Poussing (2014), and then that of Tavassoli and Karlsson, (2015) and Karlsson and Tavassoli (2016)[1]. It distinguishes between single and complex innovators by focusing on the technological and innovative capacities of firms. Technological capabilities are the set of knowledge needed to develop, produce, and sell goods[2]. The single innovator innovates in only one direction: on products or on processes. The complex innovator innovates in both directions (products and processes) and has high potential for creativity and production of new ideas compared to the company that has specialized in only product or process innovation. Indeed, synergistic relationships between product and process improvements exist, which are cross-referencing effects between different product and process research projects (Flaig and Stadler, 1994). In general, a large company has enough resources to carry out innovation projects in both directions. Firm size and complex innovation behavior therefore interact positively. The complex innovator has a broader (denser) skill base than the single innovator (Tavassoli and Karlsson, 2015). In this case, strong skills in innovation management and more generally in technology management are required in order to make the right strategic choices. The approach to the complex innovator is thus based on the state, volume, organization (or structuring) of the resources or capabilities of the companies it mobilizes.
Since the work of Kemp and Foxon (2007), environmental innovation has been considered to correspond to new 'technologies whose use is less harmful to the environment than the relevant alternatives' (Ibid., p. 2). Rennings (2000) defines this type of innovator more precisely:

[1] See also Bertrand et al. (2020).
[2] Innovative capabilities (innovativeness) refer to the knowledge needed to produce and commercialize product and process innovations (Dosi et al., 1990, p. 3).

environmental innovation corresponds to the development of new ideas, behaviors, products and processes, contributing to a reduction in environmental burdens or to ecologically-specified sustainability objectives. Environmental benefits may be the primary objectives of this innovation or may be the result of other objectives (question of intentionality). Green, sustainable, environmental or eco-innovation is systematically equated with innovation (De Marchi, 2012).

Frugal innovation (FI thereafter) is associated with three criteria suggested by Weyrauch and Herstatt (2017): substantial cost reduction, concentration on key functionalities, optimized performance level. An important consequence of this definition is that frugal products are affordable in terms of price and shape a specific offering for low-income market segments (Nunes and Breene, 2011). In short, they are more inclusive because they are much more responsive to the needs of lower-income people (Tiwari et al., 2017). In emerging economies, FIs tend to be based on a new type of entrepreneurship (Hossain, 2020). Evidence shows that FIs have moved beyond the emergence stage in developed economies (Brem, 2017; Herstatt and Tiwari, 2020). Indeed, in developed countries new frugal products are aimed at individuals in different socio-economic contexts, and not only the poorest. Frugality goes beyond the low cost of the products because its environmental benefits must be included given the standards (and regulations) in force in developed countries.

On the basis of the above definitions and characteristics of different types of innovation, we develop our hypotheses depicting the relationship between innovative behaviors and CE practices of the firm.

The environmental innovator is aware of the issues of pollution, the environment, and more generally sustainable development. Such a company can consider the benefits of CE as an extension of its ability to work positively on the environment. Moreover, many researchers consider the CE as an environmental innovation (Cainelli et al., 2010) or a driver of this type of innovation (Vence and Pereira, 2019). We can therefore predict that:

Hypothesis 1.

Being an environmental innovator increases the likelihood of engaging in circular economy practices.

Regarding the type of innovation, product innovators can develop eco-design practices for which the objective is to reduce the resource requirements and the environmental impact during the product design phase (Mendoza et al. 2017). It can encourage EC approaches where the notion of waste disappears. These eco-design practices are different from reuse, remanufacturing, recycling practices that occur at the end of the process and refer to the implementation of new processes. A priori, both types of innovators (product and process) have reasons to invest in CE. However, process innovators are more competent to implement recycling, various treatments, and reuse processes. Without excluding an impact specific to the product innovator, the following hypothesis is put forward:

Hypothesis 2.

Being a process innovator increases the probability of engaging in circular economy practices.

Innovators, who are complex because they master product and process technologies and have superior knowledge and technology management capabilities, have the cognitive and managerial resources to choose CE options. Hence, we argue the following relationship:

Hypothesis 3.

Being a complex innovator increases the likelihood of engaging in circular economy practices.

Levänen and Lindeman's study (2016) indicates that identifying frugal solutions at the micro level can help in developing CE solutions because it requires attention to local circumstances

and opportunities. Frugal innovation can be seen as a technological solution that takes natural resource and energy constraints as a starting point. It is a lever for CE (Kroll et al., 2017) because it is part of good resource management: reduction of material input in production, implementation of the repair option in case of failure, use of recycling (Albert, 2019; Herstatt and Tiwari, 2020). Hence, we argue the following relationship:
Hypothesis 4.
Being frugal innovators increases the likelihood of engaging in circular economy practices.

DATA COLLECTION

We conducted a survey of companies in the chemical industry in France. This industry is particularly relevant to our study. As a basic supplier, the chemical industry occupies a singular position in the sustainability system; it is directly or indirectly involved in most of the products manufactured, used, or consumed. Also, by modifying its environmental footprint, the chemical industry indirectly modifies those of other industries. Therefore, from a sustainable development perspective, the chemical industry can be considered as a central actor acting at the source of pollution and thus promoting the transition towards a CE.
A telephone survey was administered among 1,000 companies in the chemical industry between June 2020 and August 2020. The sample of 1,000 respondents was selected on the basis of a stratified random sampling procedure, using two representativeness criteria: company size and geographical location (see Appendix 1). Thus 53.3% of our company sample employ one to nine people (vs 52.5% according to INSEE, 2018), 29% have 10 to 49 employees (vs 30.5% according to INSEE 2018), 13.3% employ 50 to 249 people (vs 12% according to INSEE 2018) and 4.4% are large companies employing more than 250 people (vs 5% according to INSEE 2018). In addition, nearly 20.8% of the companies surveyed are located in the Ile de France, 14.2% in the Provence-Alpes-Côte d'Azur region, and 13.2% in Auvergne Rhône Alpes.
The questionnaire[3] is divided into three parts. The first part was devoted to the innovation practices of companies in the chemical industry. They were initially questioned on the different forms of innovation they have introduced over the last three years. Nearly 49% of the companies proposed a product innovation while only 36.6% of them introduced a new service. Among the companies surveyed, 50% have developed process innovations in the last three years. This first part also focused on environmental innovation practices. According to the definition used in the Community Innovation Survey (CSI), companies had to determine whether they had introduced an innovation that had a benefit for the environment. For this purpose, we distinguished nine types of environmental benefits: reduction of material resources used, energy used per unit of production, CO_2 footprint, air pollution, water pollution, soil pollution and noise pollution, elimination of hazardous materials, recycling of water or material waste. Finally, this section also analyzes the frugal innovation practices of companies, which are defined as the introduction of products that are less complex, more suitable and affordable for low-income consumers. A very large majority of the companies surveyed (68%) have adopted frugal innovations.
The second part aimed to characterize and qualify the circular economy approaches of companies in the chemical industry. In this perspective, we drew inspiration from the questions proposed by the European Commission (Ghisetti and Montresor, 2019) to define the activities

[3] This can be obtained upon request from the authors.

related to the circular economy approach. Companies were then asked to indicate whether they had undertaken the following activities, all of which fall within the scope of the CE:

- Minimize waste by recycling or reselling it to other companies (76.2%).
- Reviewing uses to minimize energy consumption (71.4%).
- Reviewing uses to minimize water consumption or maximize water reuse (66.4%).
- Modify the design of the product or service to minimize the use of materials and/or maximize the use of recycled materials (49.5%).
- Use renewable energy (22.9%).

We observe that 76% of the companies surveyed minimized waste while only 23% used renewable energy.

In this part we also asked companies about the essential factors explaining the implementation of EC practices (several answers were possible). The answers are presented in Table 1. The factors described in Section 1 (regulation, demand, technology) are listed in a hierarchy. The supply factors (technology, search for competitiveness) are ranked as most important, followed by regulation and customer pressure (demand pull).

Table 1 - The essential factors for implementing CE practices

	Yes	**No**	**Total**
Technology	46,6%	53,4%	(997)
Incentives coming from other companies in the industry	35,5%	64,5%	(995)
Customer pressure	37,4%	62,6%	(989)
Competitive advantage	47,0%	53,0%	(994)
Environmental regulations	44,3%	55,7%	(994)
Possibility to obtain public or private financial aid	24,8%	75,2%	(991)
Support for CE projects by local or political public authorities	18,6%	81,4%	(994)
Certification or standardization process dedicated to environment or ecolabels	25,5%	74,5%	(995)

Source: our own data.

Finally, the third part grouped together questions on the structure of companies, i.e. their size, their main activity in the chemical industry, but also their level of investment in R&D and their turnover.

4. ECONOMETRIC ANALYSIS, ESTIMATED MODELS AND RESULTS

Our econometric analysis aims to examine whether innovative firms have a higher propensity to engage in CE processes. It follows that this engagement must become our endogenous variable, and innovation behaviors exogenous processes. The occurrence of the former can be understood by the probability that a firm engages in circular economy processes. Y is considered as a binary random variable (whose only values are 0 or 1). All the factors that can explain this probability are designated by Xi. The latter becomes a vector of variables which is assumed to determine Y. The starting point is the Probit model, which is written as follows:

$$\Pr(Y = 1/X) = \Phi(b.X_i)$$

Pr is the probability, and Φ is the cumulative function of the normal distribution (which is different from the competing Logit model). The coefficients b measuring the impact of a variable on probability are estimated by the maximum likelihood algorithm.

Regarding the definition of the endogenous variable, several choices were possible. One could have taken one by one the questions concerning CE practices and constructed estimation protocols for each one. Our choice was to provide a better understanding of the overall behavior

of firms in this area and not to explain why they use a particular practice. Given the wide variety of engagements, which also differ in their level of intensity, we assume that it would be interesting to report on two types of engagement behavior in CE: weak or rather marginal engagement, and much stronger or consistent engagement. In this perspective, we constructed two endogenous variables (Y1, Y2). The first relates to the occurrence of weak engagement in a CE process (Ecengagweak), the second to strong engagement (ECengagStrong)[4]. Weak engagement occurs when companies answered yes at least once to questions about CE measures. Strong commitment occurred when they answered yes three times, indicating a consistent approach to circularity. The probability of each of these occurrences is explained by the same set of variables[5].
The survey results showed that many factors account for firms' investment in the CE but that technology and firm competitiveness were crucial (see Figure 1). Consistent with our research question and the hypotheses we wish to test, our econometric analysis is built around exogenous variables that relate to the innovation behavior of firms described by their occurrence. These variables will also be binary. We add control variables that can have an effect on a firm's ability to engage in circular economy practices.
Also, our variables are related to different innovation behaviors: product (InnoPro) and process (InnoProced) innovation behavior, single (InnoSimp) or complex (Innocomp) innovator behavior. With regard to environmental innovation, we define environmental innovation behavior as low (InnovEnv) and high (InnovEnvForImp) involvement. The first type of behavior corresponds to a single positive response to the eight questions concerning environmental innovation in the questionnaire, it reflects a minimum engagement in terms of environmental improvement. The second is defined as having at least four positive responses to the same questions, it is more consistent and richer in terms of diversity. We thus once again take up the problem mobilized to define our endogenous variables. We add a final (exogenous) innovation variable: frugal innovation behavior (Innofrug).
We also add as a variable of interest the firm's technological intensity measured by the ratio of R&D expenditure to sales (RDCA). This last variable is a measure of the innovative capacity of firms. The control variables relate to size, which include four possibilities (less than 10, 10 to 49, 50 to 249, 250 and more employees), and the main activity sub-sector (this variable has five possible answers: Mineral Chemicals, Organic Chemicals, Parachemicals, Soap/perfume making, and other possible sectoral affiliations). Table 2 provides the basic information on the distributions of each of the variables in our estimates.

Table 2 - Descriptive statistics of the variables

Variables	**Obs.**	**Average**	**Standard deviation**	**Min**	**Max**
CEengagweak	1000	0,25	0,43	0	1
CEengagstrong	1000	0,64	0,48	0	1
InnoPro	1000	0,60	0,49	0	1
InnoProced	1000	0,47	0,50	0	1
InnoSimp	1000	0,21	0,41	0	1
InnoComp	1000	0,43	0,50	0	1
InnoEnv	1000	0,07	0,25	0	1
InnovEnvForImp	1000	0,90	0,30	0	1
InnoFrug	1000	0,68	0,47	0	1

[4] Appendix 2 presents the questions used in the survey to construct the model variables to be estimated.
[5] The idea of distinguishing between two levels of commitment to CE finds its source in the work of Demirel and Danisman (2019) on a sample of SMEs showing that only a significant investment in CE feeds companies' economic performance.

RDCA	1000	1,26	1,41	0	4
VSE (-10 employees)	1000	0,53	0,50	0	1
SE(10-49 employees)	1000	0,29	0,45	0	1
ME(50-249 employees) (Ref.)	1000	0,13	0,34	0	1
LE(+250 employees)	1000	0,04	0,21	0	1
Others	1000	0,20	0,40	0	1
MinChem	1000	0,05	0,21	0	1
OrgChim	1000	0,18	0,38	0	1
Parachim	1000	0,04	0,20	0	1
SoapPerf (Ref.)	1000	0,53	0,50	0	1

Source: our own data.

We see that 89% of the sampled companies have a commitment to CE, although a quarter have a rather minor commitment. Table 2 reveals high propensities to engage in innovation: 60% for product innovation, 47% for process innovation. These figures are higher than those obtained from standard innovation surveys known as CIS (for France see Bertrand et al. 2020). Complex innovators are more numerous than single innovators, which is rather a surprise compared to what is known for other periods at the national level (see Le Bas and Poussing, 2014). But this can be explained by the choice of the observed industry: in chemistry there are strong interactions between product and process. A new product requires a new process, and new processes produce products that are somewhat different from the old ones. The rates of environmental and frugal innovators are very high.

The correlation table (Appendix 3) between the exogenous variables shows a strong collinearity between them. This result was anticipated, since the innovation variables are related, for example an environmental innovator is necessarily a product and/or process innovator. Therefore, we opted to include the innovation variables successively, one after the other. In other words, a different Probit model is estimated for each of the innovation behavior variables. The control variables are always present in each of the estimated models.

The question of causality must be addressed here. Our exogenous variables explain CE engagement behavior. Causality is also assumed but not demonstrated. This would require the values of the exogenous variables for the prior period. Moreover, the existence of an endogeneity bias cannot be excluded. For example, it is possible that during an investment in a CE project, the firm carries out technological innovations. However, the analysis of innovation behaviors allows us to predict the direction of the relationship between innovation and the implementation of CE projects.

Table 3 - Estimated model results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
CE engagment	**Weak**	**Strong**	**Weak**	**Strong**	**Weak**	**Strong**	**Weak**	**Strong**	**Weak**	**Strong**	**Weak**	**Strong**	**Weak**	**Strong**
InnoPro	0.18*	0.14												
	(0.098)	(0.092)												
InnoProced			-0.00	0.29***										
			(0.097)	(0.092)										
InnoSimp					0.20*	-0.24**								
					(0.104)	(0.100)								
InnoComp							0.00	0.32***						
							(0.098)	(0.094)						
InnoEnv									0.65***	-1.04***				
									(0.161)	(0.168)				
InnovEnvFortImp											-0.57***	1.12***		
											(0.137)	(0.144)		
InnoFrug													-0.04	0.68***
													(0.096)	(0.090)
RDCA	0.01	-0.01	0.03	-0.03	0.03	0.00	0.03	-0.03	0.03	-0.00	0.04	-0.01	0.03	-0.03
	(0.034)	(0.032)	(0.033)	(0.032)	(0.032)	(0.031)	(0.034)	(0.032)	(0.032)	(0.031)	(0.032)	(0.032)	(0.032)	(0.031)
VSE	0.26*	-0.24*	0.21	-0.21	0.21	-0.27**	0.22	-0.20	0.22	-0.28**	0.20	-0.25*	0.21	-0.19
	(0.145)	(0.136)	(0.146)	(0.137)	(0.144)	(0.135)	(0.146)	(0.137)	(0.144)	(0.136)	(0.145)	(0.136)	(0.145)	(0.137)
SE	0.26*	-0.16	0.24	-0.15	0.23	-0.16	0.24	-0.14	0.25*	-0.18	0.24	-0.17	0.24	-0.17
	(0.147)	(0.139)	(0.148)	(0.138)	(0.147)	(0.139)	(0.148)	(0.139)	(0.148)	(0.139)	(0.147)	(0.139)	(0.147)	(0.140)
LE	-0.02	0.01	-0.03	0.02	-0.05	0.04	-0.03	0.04	-0.04	0.01	-0.03	0.00	-0.03	0.02
	(0.248)	(0.231)	(0.248)	(0.230)	(0.250)	(0.233)	(0.248)	(0.231)	(0.247)	(0.231)	(0.247)	(0.231)	(0.248)	(0.229)
Others	0.14	-0.16	0.12	-0.16	0.12	-0.18*	0.12	-0.15	0.12	-0.17	0.14	-0.20*	0.12	-0.23**
	(0.115)	(0.109)	(0.115)	(0.109)	(0.115)	(0.109)	(0.115)	(0.109)	(0.116)	(0.110)	(0.116)	(0.111)	(0.115)	(0.109)
MinChem	0.13	-0.32	0.14	-0.35*	0.17	-0.35*	0.14	-0.36*	0.12	-0.29	0.09	-0.23	0.13	-0.28
	(0.204)	(0.194)	(0.206)	(0.195)	(0.206)	(0.194)	(0.206)	(0.195)	(0.206)	(0.192)	(0.211)	(0.197)	(0.206)	(0.199)
OrgChem	0.11	-0.19	0.11	-0.18	0.10	-0.18	0.11	-0.17	0.10	-0.18	0.11	-0.19	0.10	-0.12
	(0.122)	(0.115)	(0.121)	(0.114)	(0.121)	(0.115)	(0.121)	(0.114)	(0.122)	(0.116)	(0.122)	(0.117)	(0.122)	(0.118)
Parachim	-0.02	-0.08	-0.02	-0.09	-0.02	-0.08	-0.02	-0.09	-0.10	0.02	-0.06	-0.01	-0.03	0.01
	(0.231)	(0.212)	(0.229)	(0.214)	(0.231)	(0.215)	(0.229)	(0.215)	(0.230)	(0.225)	(0.229)	(0.227)	(0.230)	(0.219)
Constant	-1.06***	0.56***	-0.94***	0.51***	-0.99***	0.70***	-0.95***	0.50***	-1.01***	0.73***	-0.44**	-0.36*	-0.92***	0.19
	(0.162)	(0.152)	(0.159)	(0.148)	(0.152)	(0.142)	(0.158)	(0.147)	(0.152)	(0.143)	(0.196)	(0.187)	(0.165)	(0.155)
Observations	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
log-likelihood	-557.9	-645.7	-559.6	-641.5	-557.7	-644	-559.6	-640.7	-551.2	-626.1	-550.6	-613.6	-559.5	-617.7
Pseudo_R2	0.00790	0.00924	0.00494	0.0155	0.00823	0.0118	0.00494	0.0169	0.0197	0.0392	0.0209	0.0585	0.00509	0.0521
Prob > chi2	0.4496	0.2356	0.7851	0.0186	0.4196	0.0889	0.7853	0.0115	0.0082	0.0000	0.0044	0.0000	0.7706	0.0000
Correct classification	75.00%	64.50%	75.00%	64.40%	75.00%	64.40%	75.00%	64.40%	74.20%	67.40%	74.80%	69.10%	75.00%	66.40%

Robust standard errors in brackets, *** p<0.01, ** p<0.05, * p<0.1

Table 3 shows the results of the estimates. Before explaining our main results, let us start with the quality of the estimates. The pseudo R^2 are generally low, which is related to the fact that we have a reduced number of explanatory variables for each estimate, and that the survey results showed that several factors at the firm level push firms to implement CE processes. The estimates are generally significant. Many of the estimated relationships have a satisfactory number of well explained cases. This is confirmed by the test that is carried out on the value of the log of likelihood.

Regarding the coefficients, a positive and significant coefficient means that its intensification contributes to increasing the probability of implementing CE processes. With regard to the commitment to CE, being an environmental innovator has a positive effect on the decisions to carry out CE actions. But this action is complex. Being an environmental innovator with low involvement means that one behaves with low engagement in CE[6] practices. However, this is a barrier to significant investment in CE. On the other hand, a large-scale environmental innovator becomes highly engaged in CE practices, and this is a barrier to low engagement in CE. All these results are coherent with each other.

A frugal innovator always engages strongly in CE practices. This confirms the relationship that appears in recent literature between frugality and circularity (see notably Albert, 2019). The complex innovator invests strongly in CE.

By contrast, being a single innovator increases the probability of having small-scale CE practices, but only slightly and with little statistical significance. This result can be related to the fact that a complex innovator has an advantage in terms of potential for creativity and the production of new ideas compared to a firm specialized in product or process innovation. The complex innovator has a broader (denser) skill base than the single innovator (Tavassoli and Karlsson, 2015). Strong skills in innovation management and more generally in technology management are required in order to make the right strategic choices. It is therefore not surprising that it is oriented toward CE processes.

In terms of types of innovation, the estimates show that a product innovator is moving toward smaller (or more specialized) CE investments (e.g. around eco-design), whereas a process innovator has more consistent practices, investing in several dimensions of CE.

The last variable that is considered to be related to innovation behavior is the proportion of research expenditure relative to sales (a measure of the firm's technological intensity). It has no impact on the two types of firm commitment to the CE if an innovation variable is added into the equation. It is therefore not technological intensity that counts, but rather the firms' capacity to carry out innovations that plays a role in the commitment to CE processes. Our estimates predict that, in general, there is no effect of size on commitment to CE. One exception is the case of very small firms, where the associated coefficient is sometimes negative, demonstrating that having a very small size is a barrier to CE[7] investment.

In conclusion, if we are only interested in a strong commitment to CE, our four hypotheses are supported by our estimates. The case of a minor commitment can be taken into account, but the explanatory model that we use is different. The variables that are less significant are product innovation, the single innovator and the small-scale environmental innovator.

CONCLUSION AND DISCUSSION

Our general argument regarding the relationship between innovative behaviors and CE practices is largely validated by our results. Being innovative is, at least in the statistical sense, associated with a commitment to CE. There are, of course, other factors that determine the engagement of firms in

[6] It should be noted that we have not retained innovation in recycling phenomena, typical of a CE practice, as an environmental innovation, unlike what is done in community surveys on innovation.

[7] Robustness tests were undertaken to verify the stability of the results. They are not reproduced here. For example, putting the two variables innosimp and innocomp in the same equation does not change the results which stipulate that the first has only a significant effect on weak commitment and the second on strong commitment in CE. Similarly, there is very little change in the size of the coefficients (and the sign, of course) when we put in the same equation the variables that take into account the capacity to achieve environmental innovations and frugal innovation.

CE processes (our control variables account for some of them) but having innovative skills does play an important role. In comparison with the literature, two contributions are worth highlighting. First, our results validate the idea that a relationship exists between technological innovation and CE investment mainly among complex innovators (product and process innovators), and that the direction of innovation is underpinned by environmental concerns after controlling for other factors. This point means that the level of technological competence (strong among complex innovators) plays an important role in determining CE involvement.

Furthermore, it is confirmed that there is a relationship between frugality and circularity that only recently emerged in the literature. This finding represents a future research direction addressing a new issue of sustainable behavior: the relationship between circularity and frugality.

Our research question also has an analytical implication: technologically innovative processes are a solid basis for making the necessary transitions from linear to circular processes. In this respect another relevant future research direction would consist in taking into account more specifically the dimension of relations between actors (collaborations), which are voluntarily put aside in this paper. In this work, CE has been treated very globally (via the two variables of weak/strong commitment). It would, then, be interesting to introduce other variables such as organizational innovation and business model innovation, which take into account the relationships with other players in circular systems.

Studying a single sector (the chemical sector) with control variables for sub-sector membership in the estimates gives more stability to our results. However, given the importance in the field of pro-environmental behavior of the specificities of industries (see, among others, Antonioli et al., 2013), a generalization of our results would be important. It therefore remains to explore what can be generalized and what remains specific.

Our work has a public policy implication. Since innovative firms are ‘naturally’ oriented towards CE, the public authorities should focus on firms that are not (not very) innovative to provide information, awareness and incentives related to the transition toward the CE.

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APPENDICES

Appendix 1 - Sample Representativeness by Size and Region

Company Size	Proportion Sample	Proportion INSEE 2018
0 to 9 employees	53.3%	52.5%
10 to 49 employees	30.5%	30.5%
50 to 249 employees	13.3%	12%
+250 employees	4.4%	5%

Région	Proportion Sample	Proportion INSEE 2018
Ile de France	20.8%	21%
PACA	14.2%	14%
Auvergne Rhône-Alpes	13.7%	13.5%
Occitanie	9.4%	9%
Nouvelle Aquitaine	8.5%	8%
Haut de France	7.1%	7%
Grand Est	6%	6.5%
Normandie	4.4%	5%
Bretagne	4.2%	4%
Centre Val de Loire	3.6%	4%
Pays de Loire	3.4%	3.5%
Bourgogne Franche Comté	3.2%	3%
Corse	1.5%	1.5 %

Appendix 2 − Definition of the main variables of the estimated model

Variables	Questions Asked of Sampled Firms
InnoPro	During the past three years has your company introduced new or significantly improved goods (excluding the single resale of new goods purchased from other companies and exclusively cosmetic modifications)?
InnoProced	In the past three years, has your company introduced any significant new or improved features to your manufacturing or production processes for goods or services?
InnoEnv et InnovEnvFortImp	During the last three years has your company introduced: an environmental innovation which consists of the introduction of an innovation in product (good or service), process, organization or marketing that generates the following environmental benefits compared to alternatives 1. a reduction in the material resources used 2. a reduction in the energy used per unit of production 3. a reduction of the CO_2 footprint 4. a reduction in air pollution 5. a reduction in water pollution 6. a reduction of soil pollution 7. a reduction in noise pollution 8. a removal of hazardous materials

InnoFrug	In the past three years, has your company introduced products that are less complex, more suitable and affordable for lower-income consumers?

Appendix 3 - Correlation between Variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) InnoPro	1.000											
(2) InnoProced	0.606***	1.000										
(3) InnoSimp	0.217***	-0.282***	1.000									
(4) InnoComp	0.712***	0.920***	-0.446***	1.000								
(5) InnoEnv	-0.050	-0.082***	0.044	-0.085***	1.000							
(6) InnovEnvForImp	0.100***	0.127***	-0.034	0.127***	-0.817***	1.000						
(7) InnoFrug	0.365***	0.326***	0.009	0.342***	-0.135***	0.187***	1.000					
(8) RDCA	0.375***	0.369***	-0.021	0.380***	-0.034	0.057*	0.157***	1.000				
(9) TPE	-0.262***	-0.287***	-0.002	-0.274***	0.002	-0.058*	-0.163***	-0.336***	1.000			
(10) PE	0.103***	0.122***	0.018	0.105***	-0.000	0.029	0.097***	0.127***	-0.683***	1.000		
(11) ME	0.172***	0.186***	-0.042	0.196***	-0.002	0.032	0.079**	0.189***	-0.418***	-0.250***	1.000	
(12) GE	0.127***	0.120***	0.034	0.110***	-0.001	0.023	0.053*	0.224***	-0.229***	-0.137***	-0.084***	1.000

*** p<0.01, ** p<0.05, * p<0.1