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A FRUGAL INNOVATOR IS A COMPLEX AND ENVIRONMENTAL INNOVATOR. EVIDENCE FROM THE FRENCH CHEMICAL INDUSTRY

Mounir AMDAOUD et Christian LE BAS

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ESDES - UCLy
10, Place des Archives
69288 Lyon Cedex 02

Mail : isbo.esdes@univ-catholyon.fr

A frugal innovator is a complex and environmental innovator. Evidence from the French chemical industry

Mounir Amdaoud, Chercheur rattaché à EconomiX, (CEPN, CNRS, Paris Nord University)

Email: mounir.amdaoud@economix.fr

Orcid number: 0000-0003-2148-6532

Christian Le Bas, Full Professor of Economics (Esdes, UCLy)

Email: clebas@univ-catholyon.fr

Orcid number: 0000-0002-6640-7255

Abstract

Frugal innovation establishes a type of innovation that is experiencing strong development in industry all over the world. Although many papers deal with frugal innovators, there is little work that analyses what type of innovator this is. We fill this gap through the study of a sample of a thousand French chemical firms surveyed by phone. In the questionnaire one question focused on their ability to carry out frugal innovations. Due to the interdependence and simultaneity between the different Schumpeterian strategies of innovation (product, process, single, complex) performed by the firms we estimate two Multivariate Probit Models. A first set of findings indicates an unobservable factor increase, both in the probability to innovate frugally and the probability to achieve product or process innovation. Nevertheless, there is a more intense relationship between frugal innovations and product innovations compared to those in process. Environmental innovators and frugal innovators are interrelated. The most important result confirms the complementarity between frugal innovation and complex innovation strategy (product and process innovation). Investing in R&D sets up a driver of frugal innovation along the lines of what the literature tells us. The final interesting result: a link emerges between investing in Circular Economy practices and frugal innovation.

Key words: Frugal innovation, product innovator, process innovator, environmental innovation

Codes JEL: O1, O14, O33, Q5

Introduction

Frugal innovation is gaining momentum as a viable new type of technological innovation in developing, as in developed, economies. Indeed, Frugal innovation (FI thereafter) is becoming an important topic in the field of innovation management and innovation studies. The systematic review of the literature carried out by Pisoni et al. (2018) shows that there was no publication between 1990 and 2004. In contrast, they selected 118 papers from 2005 to 2017. 59% focused on emerging or developing countries and 36% on developed countries. Updating their study thanks to Scopus we discover 135 papers from 2017 to 2021. While the FI definition is still not stabilised, we draw on the work by Weyrauch and Herstatt (2017) suggesting three criteria for characterising FI: substantial cost reduction, concentration on core functionalities, and optimised performance level in order to serve low-income consumers. This definition is large and could be associated with different configurations in terms of innovations. It means that FI very often implies a change in the product (product innovation). Sometimes this may be minor changes. Furthermore, FIs are often achieved by process innovation involving substantial cost reductions. Often does not mean always. There are cases for which a cost reduction is not related to innovation in the production process. For instance, let us suppose a manufactured product having fewer elements or sub parts matching a characteristic of frugality. When it is manufactured through the same process it will be produced with a cost reduction (the firm saves materials). As a result, frugal product innovation does not imply a process innovation[1].

There is now a consistent literature mainly focused on FI properties, its forms and its consequences (Le Bas, 2017; Pisoni et al., 2018; Hossain, 2020); by contrast we find only a few items of literature addressing the issue of the type of innovator behind a frugal innovator. In the Schumpeterian approach of innovation, we consider product innovation and process innovation as the most important type of innovation, with crucial consequences for the innovating firm in terms of strategic positioning, competition, and profitability (Fagerberg et al., 2005). As a result, the important issues are: does a frugal innovator innovate in its

[1] Let us take an example in the chemicals industry. In this industry the final stage establishes a mixing of various components; let us suppose that there are fewer components to be mixed. The process of mixing can be an achievement with the same technological system. Consequently, there is no process innovation but the firm can produce with fewer costs.

products? In its processes? Moreover, recently a new innovation taxonomy has emerged (Le Bas and Poussing, 2014; Tavassoli and Karlsson, 2015) emphasising a single innovator (innovating in product *or* in process) and a complex innovator (innovating in both product *and* process[2]). Is a frugal innovator rather a single or complex one? Besides, can it innovate in other directions? In the field of the environment? Is it also an ecological innovator? It is important to know what type of innovator a frugal innovator is in order to understand what its innovation strategy is, on the one hand, and to try to figure out the likely trend of FI diffusion, on the other.

Our research topic can be formulated as: knowing that a firm has innovated frugally, what is the underlying innovation strategy behind product or process innovation strategy? If FI very often implies a change in the product it is an open question to know if this innovator is also a process innovator or if it establishes a complex innovator strategy. Our research question can be formulated simply: knowing that a firm innovates frugally, we want to know if it innovates in its product, or process, or both product and process? The answers to these questions allow us to better understand which innovator is a frugal innovator, to have a clear idea of the strategy that is implemented. Such questions are still unexplored by the literature. Incidentally, we aim to look at whether a frugal innovator could innovate in another direction than frugality, in the environment for instance.

We contribute to the literature in another, more theoretical, way. When the literature deals with FI it very often does that without any direct references to Schumpeter's work on innovation. Schumpeter (1934) distinguished between different basic types of innovation, among them product, process, and organisational innovations and the likely various combinations between them (see the handbook edited by Stoneman (1995) or the work by Antonelli (2008)). This range of choices established the innovation strategy of firms. Surprisingly we have not seen any study that investigates characteristics, enablers, drivers, barriers of FI with references to the Schumpeterian choice in innovation strategy. In this paper we investigated FI in a Schumpeterian way by focusing on various choices that firms innovating frugally make in their innovation strategies. Such a research question can provide interesting materials for designing a coherent macro innovation policy or strengthening strategic consulting expertise.

[2] We return to these definitions in Appendix A.

This paper aims to identify the kind of innovation underlying technological frugality and to consider in which other directions frugal firms could innovate as well. Our empirical data are supported in a survey carried out on the French chemicals industry (Arfaoui et al., 2020). We gather relevant information on firm innovation behaviours through a survey on the population of a thousand firms. We use the responses to carry out statistical and econometric exercises showing the various types of innovations undertaken by a frugal innovator.

It is relevant to make an important distinction between FI in developing economies and FI in developed economies. In the first, we find a "resource-constrained" ecosystem characterised by scarcity of financial and human resources, a weak innovative culture and infrastructure, and institutional failures (Pisoni et al, 2018; Ploeg et al., 2020). All these factors can work as enabling drivers in the creation of frugal new products (Pansera and Owen, 2015; Sharma and Iyer, 2012). In developed economies other factors are more important. Northern firms wishing to design and manufacture new frugal products have to invest resources in R&D activity to develop new frugal products. As a result, because it has invested resources in R&D, a frugal innovator is surely already a technological innovator. FI in the North has basic characteristics: cost effectiveness and environmental sustainability (Tiwari and Bergmann, 2018). These features can be achieved by the simplification of the design and production process, as well as by eliminating avoidable complexity through standardisation[3].

The paper is organised as follows. Section 1 sets out the literature and identifies the main gaps. The analytical framework shapes the frame of Section 2. Then our hypotheses are presented (Section 3). Section 4 is devoted to our data, the variables definition, and a first statistical descriptive overview. The following section (Section 5) gives details on the econometric strategy, the empirical models that we test. In the last section (Section 6) we delineate our results before examining their discussions.

Section 1. What this tells us about the literature on frugal innovators and what are the gaps that we fill

There has to date been abundant literature on FI innovation. There is a lot of information available through the literature. This provides many examples of new frugal-type products (see among others: Lim and Fujimoto, 2019; Von Janda et al. 2020); however, there are also

[3] Two important trends can explain why a firm develops FI in the North. Upcoming market saturation tends to characterize many industries. In this context, FI could be a good lever for boosting demand. On the other hand, when large incumbent firms innovate frugally, they prevent competitors, or even possible entrants, from doing so. Consequently, they avoid competition from a disruptive innovator.

some much rarer studies which emphasise new frugal processes of manufacturing (Brem and Wolfram, 2014). In general, we have little information on the innovator who developed and implemented this type of innovation unless the company is either very well known, such as the emblematic example of the Tata company which developed the Nano car, or such as the case of two manufacturers, which has been described in an academic work by Corsini et al. (2021). Many specific cases are also described in professional journals. Nevertheless, little is known about whether the company implementing FI is also acknowledged as being innovative in other non-frugal technologies, at what scale this is, and what could be its overall Schumpeterian innovation strategy. Until now, we have been inclined to recognise the literature on FI and that on non-frugal technologies (much older and much denser) develop in isolation. This sets up serious limitations because it seems to us to be important to know if the firm is a frugal innovator, how it innovates, and understand the relation between frugal and other types of innovation that could be implemented. As a result, it works to build up a new research programme (and new corpus) interweaving the study on FI and the standard innovations studies based on the Schumpeterian approach of innovation strategies (product innovation, process innovation, and complex innovation which combines the first two). There are several motivations for this. First, the co-evolution of different types of innovation is a crucial lever of firm performance (Damanpour and Aravind, 2012; Karlsson and Tavassoli, 2015; Tidd and Bessant, 2020). Second, and more important for our research, the type of strategy followed by the firm can be a support in creating and inventing technological frugal solutions. Complementarities may arise between the development of non-frugal technologies and those that are frugal. There are cross exchanges between bodies of knowledge[4]. In other words, frugal innovators do not act as if they are on a "frugal island", they live and evolve in environments (including their own firm's organisation) in which technologies (not frugal) are predominant. Overlapping between the two groups of bodies of knowledge is a matter of fact. The current work offers significant improvements in that direction.

Assuming that the diverse types of innovation are linked, our frame is close, but not identical to, another one, labelled *complementarity in innovation* (Mohnen and Röller, 2005; Polder et al., 2010). As stated by Mohnen and Röller (2005): a group of activities is complementary if doing more of any subset of these activities increases the returns from doing more of any subset of the remaining activities. This complementarity approach supposes that we calculate

[4] Recently Barbieri et al. (2020) find out the development of green technologies strongly relies on advances in other green and in particular non-green technological domains.

a performance (productivity) index as a measure of the effects of the various types of innovation behaviour. In this paper we do not follow this approach.

How to operationalise our ideas? The firm's innovation process is channelled by an explicit innovation strategy that aims to invest resources (human and material) in innovation activity and to guide the efforts of firms towards innovation goals and market targets. Innovation strategy can be analysed through various approaches of innovation: that of the Strategic Management of Innovation (Tushman and Anderson, 2004), that of the Economics of Innovation (Antonelli, 2011; Stoneman, 1995), that of Innovation Studies (Fagerberg and Verspagen, 2009; Martin, 2016). A better empirical understanding of innovation strategy has been achieved recently with the persistent diffusion of innovation surveys (the so-called CIS). They are coherent with a neo-Schumpeterian frame in which firms have the opportunity to choose an innovation strategy involving a combination of product, process, marketing or organisational innovation[5]. When we consider technological innovators the distinction between product and process innovator is of paramount importance[6]. The two match different market strategies. Pianta (2005) showed that the strategies of process innovation are associated with *price* competitiveness, by contrast strategies of product innovation are linked to *technological* competitiveness (technological leadership). When firms decide to engage in only one type of innovation that can be termed as a "single" innovation strategy (Le Bas and Poussing, 2014). In contrast, empirical works have shown that innovative firms combine various types of innovation at the same time and that this becomes a "complex" innovation strategy (Le Bas and Poussing, 2014; Tavassoli and Karlsson, 2015). As a consequence, the gains of complex innovators are twofold. With the new products (or improved products) they open new markets (taking competitive advantages), and with cost-reducing process innovations they can increase the level of demand for their products. The scale of complex innovators' commercial success enables them to achieve better profitability.

Taking into account what the literature tells us it seems relevant to examine the relationships between the strategies of product/process and single/complex innovators, on the one hand, and FI behaviour on the other. It allows us to address questions such as: does a product (versus) a process innovator have a greater propensity to innovate frugally? Are complex innovators better placed for implementing FI than single ones? The answers to these questions would allow progress in the research question that we want to develop, namely, what are the

[5] In this research marketing innovation will not be considered due to lack of reliable data.
[6] Appendix A gives more details on the various types of innovation we mobilise in our study.

interactions between FI and the general behaviour of innovation? Until now we have examined types of innovation behaviour; we find it equally relevant to envisage the directions taken by innovation strategies. For instance, due to climate change challenges, so-called environmental innovation is of crucial importance. As a result, looking at whether there is a link between FI and the occurrence of being an environmental innovator has many economic and social implications. Here we assume that environmental innovation and frugal innovation are close. Innovating in the environment could trigger FI.

Section 2. Analytical framework: competence-based perspective and theory of recombination

Two theoretical frames can be put forward for accounting for our approach. They have their theoretical roots in the Schumpeterian vision of innovation. In the first place there is a competence-based perspective. This framework stipulates that technological innovation is associated with dynamically increasing returns in the form of learning-by-doing (Arrow, 1971), learning-by-using (Rosenberg, 1982), and learning-to-learn (Stiglitz, 1987), which enhance knowledge stocks and the probability to find innovations. R&D activities equally augment firms' technological competencies to learn about new knowledge developed elsewhere (Patel and Pavitt, 1995). Learning establishes the firm's capacity to innovate in the future because, through its R&D, the firm explores a process of learning and can discover useful ideas (Cohen and Levinthal, 1990). Through innovation the firm encompasses the development of new ideas transformed into marketable products and processes. A firm explores and/or exploits technological opportunities for creating new useful artefacts (Pavitt, 2005). This perspective provides an appropriate approach for our research: accumulating ideas and knowledge allows the firm to search effectively in many directions (and not only in the direction it has innovated) while the search through a path-dependent activity gives more change to succeed to local search (Fleming, 2001). Research and innovation activity are finalised, a firm search in certain directions. This framework of analysis centred on the accumulation of knowledge tells us that a firm that invests in knowledge activity (in Research and innovation activity) will have more chance to innovate frugally. Our framework tells us that this is where the accumulation of knowledge occurs, where FI could be produced. Does this contradict the idea supported by Ploeg et al. (2020) that internal resource-poor environments are drivers of FI? Ploeg et al. (2020) apply this idea to LDC companies, therefore to environments where the accumulation of firm internal knowledge is very often insufficient. The frame we build up is related to firms in developed economies.

A second frame is equally useful. Frugal and non-frugal innovation could be linked within the same firm because of a fundamental characteristic of innovation: every innovation consists of new combinations of existing pieces of knowledge (or ideas). The greater the variety of these elements within an organisation the greater the scope for them to be combined in different ways (Fagerberg et al., 2005) and the greater will be the propensity to find potential innovations. New useful knowledge is often produced by recombining scattered existing pieces of knowledge (Fleming 2001; Keupp and Gassmann, 2013; Weitzman, 1996)[7]. It follows that a firm that has recombined in the past (through the innovation process) will have more experience in testing new combinations, including new frugal technological pieces[8]. An important point in the theory of recombinative innovation or knowledge recombination (rightly underlined by Keupp and Gassmann, 2013) is that outcome of a recombination of existing bits of knowledge that are internal to the firm, but also of a recombination of existing bits of knowledge with new external knowledge elements. The latter is important in our vision because some new elements of frugality (coming from the outside) can be put in the process of recombination. The firm's capacity to learn about recombination, as all aspects of firm learning, necessarily includes an absorptive capacity of external knowledge (Cohen and Levinthal, 1990). We can assume in our empirical work that the knowledge about the tastes and wants of customers are particularly crucial for designing a frugal product accepted by the market.

Our framework differs from that put forward by Ploeg et al. (2020). They argue that the firm's resource constraints could be a driver of frugal innovation. They suggest two ways of designing the potential effects of resource constraints on innovation. The first is related to *internal* resource constraints through innovation. The authors note that, in the case of internal resource constraints, firms search for solutions that cut cost, through strategies such as the substitution of input materials for cheaper alternatives, energy efficiency measures, or vertical

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[7] Other basic references related to this approach are: Galunic and Rodan (1998), Henderson and Clark (1990), Utterback (1994).

[8] Nevertheless, the process of recombination appears more complicated. If we support the idea that frugality constitutes a new paradigm, it is not certain that a firm having accumulated non-frugal knowledge could easily integrate elements of knowledge based on frugal principles. The high-tech culture of engineers can shape an obstacle to the development of technological devices that are not "over engineered".

integration to reduce expenses. In this context, the innovations are a means for reducing the constraints that cannot be solved with existing methods. Ploeg et al. (2020) point out that the conducts are rather linked to a 'good enough' standard of performance acceptable to stakeholders or shareholders. Ploeg et al., (2020) support the idea that there is a second approach: resource constraints can affect the firm's *environment* as a whole. It shapes the problems of customers and various economic players "and thereby also the opportunity space for firms that are aware of these problems and have a potential solution, often an innovation". This type is more frequent in LDCs in which the customers are poor. It is true that resource scarcity stimulates managers to build up new management practices that foster the search for new opportunities. The idea that a certain scarcity located in sectors can trigger innovative responses from firms is a strong invariant of the historiography of technological change (see Rosenberg, 1973). But there is no reason to think that these difficulties push FI more than other types of technological innovation. Keupp and Gassmann (2013) construct analytical support for the hypothesis that knowledge constraints (an internal resource constraint according to the taxonomy by Ploeg et al., 2020) spur *radical innovation* and partial support for the hypothesis that financial constraints spur radical innovation. As a consequence, resource constraints would not push firms towards frugal technologies even if they can trigger the search for new technological devices.

Section 3. Hypotheses: linking frugal innovator, types of innovation and environmental purposes

Our work will concern three aspects of firm innovation activity: product/process, single/complex, environmental/non-environmental. For each of these we delineate hypotheses to be tested.

Regarding the product innovator we follow the analysis by Pianta (2005). At its level, there is a correlation between the search for a technological leadership, the strong accumulation of technological knowledge, and the target to master more of a knowledge base. The first topic of a theoretical framework applies well in this context. The process innovator concerned by cost-cutting achievements can be content with incremental innovations in the technological lines already in force. Consequently, we are inclined to consider:

Hypothesis 1. A product innovator innovates frugally with a higher probability than a process innovator.

Besides product and process innovator our analysis includes two other categories: *Single Innovator* and *Complex Innovator*. This taxonomy, introduced by Le Bas and Poussing (2014) and Tavassoli and Karlsson, (2015) has important dynamic implications. A single innovator innovates in only one direction: on products or on processes. The complex innovator innovates in both directions (products and processes). It has a high potential for creativity and the production of new ideas, compared to the company that has specialised in only product or process innovation. Indeed, we would like to study if a single innovator (a product *or* process innovator) has a higher (smaller) propensity to innovate frugally than a complex innovator (product *and* process innovator). Reinhardt et al. (2018) point out certain practices are more important for low-end than for regular innovation. For example, they remark simultaneous product and process innovation is very important low-end innovation capability dimensions. What is an argument for linking complex innovator et frugality.
As a 'complex' innovator, the organisation works in two directions (products and processes). It has one advantage in terms of the potential for creativity and new ideas in comparison with the firm that is more specialised (on product or on process). Moreover, it may be that there are synergetic relations between improvements to the products and improvements to the processes. As a result, a complex innovator recombines more. The new knowledge generated through the research that is carried out, looking for product improvements, can spill over to the research projects aiming to improve processes. Flaig and Stadler (1994) argued that there are some spillover effects from product to process innovations and vice versa. The second topic of our theoretical framework related to innovation by recombination applies here. As a result:

Hypothesis 2. A complex innovator has a higher probability to innovate frugally than a single innovator

The last category of innovator: environmental innovator. It is important in the context of climate change and of the transition towards more sustainable growth and development. According to Kemp and Foxon (2007), environmental innovations correspond to new 'technologies whose use is less harmful to the environment than the relevant alternatives' (Ibid., p. 2). FI saves an absolute amount of raw materials, inputs, and other physical resources. As a consequence, the pressures on natural resources are weaker. FI increases the sustainability of the economy (Le Bas, 2020). FI reinforces the strength of the mechanisms of a circular economy (Brem and Ivens, 2013). We know that there is a close relationship between a frugal product and a more frugal manufacturing process. It is encapsulated in the term frugal engineering innovation (Brem and Wolfram, 2014). It means that such a process of manufacturing is designed to save resources and energy. In accordance with this recent literature we consider FI as a "kind" of environmental innovation (Le Bas, 2020); our hypothesis will be that:

Hypothesis 3. Environmental innovator and frugal innovator are related

An important feature that emerges in the recent literature on FI is the relation between frugality and the circular economy (Albert, 2019) as opposed to the model of the linear economy. It leads to the idea that the implementation of circular economy (CE thereafter) practices matches investment in a frugal system of production. Therefore, we anticipate a positive relation between environmental innovator and frugality, we consider the same for the firm that invests in CE. As a result, we conjecture that:

Hypothesis 4. A firm with a strong engagement in circular economy practices has a higher probability to innovate frugally.

Section. 4. Data, variables definition, and first statistical descriptive overview

In this study we use a survey carried out on 1,000 companies from the French chemicals industry. As far as sustainability and environmental innovation is concerned this industry has a strong impact on the industrial system because, through its products, it is more or less involved in other industries located downstream. This telephone survey was realised by a private service company in summer 2020. We have a sample of 1,000 respondents selected on the basis of a stratified random sampling procedure, meeting two criteria: company size and geographical location.

We draw on the methodology developed for the implementation of the Community Innovation Survey (simply CIS thereafter). The CIS aims to survey enterprises in order to gather useful relevant information on their innovating activity. Regarding recent research on FI, this utilises quite detailed descriptions of innovations to distinguish frugal from non-frugal innovation (Ploeg et al. 2020, Von Janda et al. 2020). Their methodology can be classified as an innovation counting method. Such a method, used by Ploeg et al. (2020) to find frugal innovations, is really interesting. In contrast, our way of counting aims to gather information on innovators and not on the innovation implemented. As a consequence, we are in the context of the innovator counting method. In empirical studies on innovation activity the opposition between the two families of counting goes back in time (Cohen, 2010). In our approach we are less interested by the technological content of FI than the occurrence of innovating frugally and therefore on innovator behaviour. Our methodological approach based on innovator counting matches the path followed for 20 years by the so-called CIS innovation surveys. This has imposed itself and has been able to produce several waves of CIS data on the innovative activities of European firms, providing a useful picture related to diverse kinds of innovation. The CIS methodology is now proven. As with CIS our approach relies on a single question in order to determine whether a company is a frugal innovator. A recurring criticism of this methodology is that it leaves room for interpretation and of many companies classifying themselves as an innovator. Nevertheless, the risk is known but weak. We think the CIS approach is in fact rather complementary to the approach based on innovation counts. It should be noted that to date we have very few statistical surveys on the number of FIs and the proportion of firms that implement this. As far as FI statistical data are concerned we are in an exploration phase related to measurement methodology. As a result, it would be awkward to reject supposed untrustworthy (or not reliable) investigations like ours which are based on firm declarations. Appendix B gives details on the definitions related to firm innovation behaviours.

The central question is about FI. In order to gain a picture of FI propensity we asked the firm the following question: *In the past three years, has your company introduced products that are less complex, more suitable and affordable for lower-income consumers?* The question is consistent with the standard definition of FI: less technological complexity, more appropriate product, affordable price. Our work provides inputs to appreciate the scale of the phenomenon of technological frugality in relation to the various types of innovation implemented by firms. Such proportions can appear to be (too) high. Regarding frugal innovation, the problem is that to date we have no benchmarks. The work by Ploeg et al. (2020) provides much lower proportions of frugal innovations (a statistical prevalence of 5%) but they focus their study on LDC firms. The recent study on Spanish firms by López-Sánchez and Santos-Vijande (2022) gives evidence close to ours as far as the propensity to innovate frugally is concerned.

We obtained information on the various Schumpeterian types of innovation implemented by each firm. We have information on whether the firm innovates or not, and the type of innovations implemented (product, process), through questions related to the company's innovative activity using the well-known definitions retained by the Community Innovation Surveys. In our sample we obtain 60% of product innovator firms and 47% of process innovators. Otherwise, 90% of surveyed firms declare that they have implemented at least one type of environmental innovation in the past three years. The reader can think that the product and process innovation rates we report are extremely high (60% and 47%). According to the data taken in the more recent EU score board for France and after adding the firm proportion for in-house product innovators with market novelties, in-house product innovators without market novelties, and innovators that do not develop innovations themselves, we found a prevalence of 38.4% for product innovators. In other words, almost 40%. But this result is related to the industry as a whole. Chemicals, our sector under observation, a medium-high-technology industry, is more high-performing in terms of innovation than many others and undoubtedly more innovative than the average of the industry. As a consequence, the proportion we find (60% of product innovators) for chemicals is entirely consistent with the EU score board (whose data comes from the CIS). On the other hand, the CIS survey gives the following results for France (from 2016 to 2018) and the whole of the industry: 37% of innovative products and 43% of process innovators (source: INSEE website[9]). For firms with 250 employees the proportions are respectively 57% and 61%. This is not too far from our results (60% and 47%). As a consequence, we argue that our results are rather reliable and in line with what we know about innovation prevalence in France. Regarding environmental innovators, we have been working on a chemicals industry that is very innovative, all kinds of innovation considered. It should be taken into account that the chemical companies have been subjected to strong pressure from the European authorities to implement devices that improve the environment (see for example the REACH programme: https://www.acte-international.com / web / paw_6949 / en / european-reach-regulation). We also know whether the firm implements environmental innovations and what are the types of improvements that it carries out (each firm could choose among eight responses that are mutually compatible). Consequently, over a period of three years, companies implementing at least one environmental innovation (technological or in organisational or packaging methods) cannot be considered exceptional. As a consequence, a rate of 90% of the firms having innovated (whatever is the innovation, including organisational innovation) in the environment is not surprising.

[9] Public French Institute of Statistics

Finally, regarding circular economy (CE) practices, companies were then asked to indicate whether they had undertaken the following activities (the proportion of yes in brackets):

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

We build a variable picturing a strong commitment in CE (*CEengagstrong*). This occurs when the firms answered yes to the question related to CE three times, indicating a consistent approach to circularity. This variable is interpreted as a measure of the ability of firms to actively open up to exchanges with other organisations, including in the field of technology, to engage in eco-innovation networks, and to be able to modify their Business Model in favour of circularity (Lopez et al., 2019).

The survey enables us to assess the effects of several important phenomena. We have information on the proportion of turnover spent on R&D expenditure (variable: *RDCA*). This variable sets up a measure of the innovative capacity of firms viewed from the input side. The class of employees in which the firm is located sets up an important control variable. This variable has three modalities: very small enterprise (variable: *VSE*), small enterprise (variable: *SE*), medium enterprise (ME), large enterprise (variable: *LE*)[10]. We have an indication that, if the firm has obtained an environmental certification (variable: *EnvCertif*) it are supposed to be more inclined to invest in an environmental innovation system (according to the study by Ren et al., 2021). We know if the relation with other economic players is rather BtoB (binary variable: *BtoB*). The idea behind this latter variable is that the firms should have a frugal innovation behaviour that is very different (less important) when they are integrated into a BtoB system than firms directly facing the consumers. In order to test the impact of internal resource constraints on the FI decision, in the estimations we put a binary variable indicating if the firm suffers from a lack of internal competence (variable: *LackInternSkil*). The latter phenomenon is considered as a crucial driver of FI (Ploeg et al. 2020).

The data for calculating the endogenous variables are directly given for each firm by the responses to the questionnaire. As a consequence, we can calculate the empirical probability to carry out frugal innovation (*Innofrug*), to innovate in the product (*Innoprod*), or to innovate

[10] For their accurate definitions see the next section.

in the processes (*Innoproced*). We define environmental innovation behaviour (*InnoEnv*) as having at least one positive response to the eight questions asked to the firm regarding conduct with respect to the environment (which is a very broad definition).

As far as exogenous variables are concerned we have:

- A variable related to the firm's technological intensity measured by the ratio of R&D expenditure to sales (*RDCA*).
- The control variable related to firm size includes four alternatives (less than 10, 10 to 49, 50 to 249, 250 and more employees). The variables are VSE, SE, LE (medium sized enterprises – 50 to 249 – set up the reference variable in the estimation.
- We include a variable taking into account a strong commitment to CE (*CEengagstrong*). This occurs when the firms answered yes to the question related to CE at least three times.
- Then we have three variables previously defined: *EnvCertif, BtoB, LackInternSkil*
- The main activity sub-sector is also controlled through five modalities: Mineral Chemicals (*MinChem*), Organic Chemicals (*OrgChim*), Parachemicals (*ParaChim*), Soap/perfume making, and other possible sectoral affiliations (*Others*).

Table 1 provides short definition and basic information on the distributions of each of the variables.

Table 1. Definition and descriptive statistical analysis of variables

Variable	**Definition**	**Average**	**Standard deviation**
InnoFrug	1 if the firm introduces at least one frugal innovation into the market in year t, 0 otherwise.	0.68	0.47
InnoPro	1 if the firm introduces at least one product innovation into the market in year t, 0 otherwise.	0.60	0.49
InnoProced	1 if the firm introduces at least one process product innovation into the market in year t, 0 otherwise.	0.47	0.50
InnovEnv	1 if the firm introduces an environmental innovation into the market in year t, 0 otherwise.	0.90	0.30
InnoSimp	1 if the firm introduces at least one product innovation or one process innovation into the market in year t, 0 otherwise.	0.21	0.41
InnoComp	1 if the firm introduces at least one product innovation with at least one process innovation into the market in year t, 0 otherwise.	0.43	0.50
RDCA	Ratio of R&D expenditure to sales of the firm	1.26	1.41
VSE (-10 employees)	1 if the firm has less than 10 employees, 0 otherwise	0.53	0.50
SE (10-49 employees)	1 if the firm has 10 to 49 employees, à otherwise	0.29	0.45
ME (50-249 employees) (Ref.)	1 if the firm has 50 to 249 employees, 0 otherwise	0.13	0.34
LE (+250 employees)	1 if the firm has more than 250 employees, 0 otherwise	0.04	0.21

CEengagstrong	1 if the firm has a strong engagement to CE, 0 otherwise	0.64	0.48
EnvCertif	1 if the firm has an environmental certification, 0 otherwise	0.30	0.46
BtoB	1 if the firm is in a BtoB context, 0 otherwise	0.67	0.47
BtoC (Ref.)	1 if the firm is in a BtoC context, 0 otherwise	0.33	0.47
LackInternSkil	1 if the firm suffers from a lack of internal skills, 0 otherwise	0.31	0.46
MinChem	1 if the firm is in the Mineral Chemicals sector, 0 otherwise	0.05	0.21
OrgChim	1 if the firm is in the Organic Chemicals sector, 0 otherwise	0.18	0.38
Parachim	1 if the firm is in the Parachemicals sector, 0 otherwise	0.04	0.20
SoapPerf (Ref.)	1 if the firm is in Soap/perfume making sector, 0 otherwise	0.53	0.50
Others	1 if the firm is in another sector, 0 otherwise	0.20	0.40

All the variables are dichotomous, excepted RDCA which is a continuous variable

As a first insight we have calculated the proportion of frugal innovators for each type of innovator (Table 2). Interestingly, the highest share is related to complex innovators. Such a result is due to the significant weight of frugal innovators innovating in process.

Table 2. Types of innovation and frugal innovator rate

	Product Innovator	**Process Innovator**	**Single Innovator**	**Complex Innovator**	**Environmental Innovator**
Frugal Innovator	82.08%	84.26%	68.90%	86.48%	71.00%

These results based on descriptive statistics need to be confirmed by a richer multi-variables analysis.

Section 5. Econometric strategy and Empirical models.

The occurrence of being a frugal innovator can be approximated by the probability that a firm chooses a frugal new technology. We are in a frame of the binary random variable model (whose only values are 0 or 1). As a result, the Probit model is a good candidate for the exercise of estimation.

A first aim of our econometric exercise is to find a significant relation between undertaking frugal technological improvements and being an innovator in other *technological directions* as a product versus process innovator, single versus complex innovator - or environmental innovator. We want to also test the possible link between these variables. The problem we face is that the variables related to the different directions of innovation are correlated (by nature) as shown in the table of Appendix C. A frugal innovator is also (and necessarily) a product or a process innovator. Otherwise, the occurrence to innovate frugally and the occurrence to be an environmental innovator are linked (we can even consider FI as a variety of environmental innovator). As a consequence, we cannot estimate a simple Probit model in which the probability to be a frugal innovator would be the endogenous variable and the occurrence to be other types of innovator exogenous variables.

The empirical specification of the decision of choice in relation to innovation types can be modelled in two ways, by either multinomial or multivariate regression analysis. One of the underlying assumptions of multinomial models is the independence of irrelevant alternatives; that is that the error terms of the choice equations are mutually exclusive (Greene, 2003). However, the choices across the type of innovation outcomes are not mutually exclusive, as firms can choose more than one innovation strategy at the same time and therefore the random error components of the innovation types may be correlated. Therefore, we use multivariate modelling, which allows for possible contemporaneous correlation in the choice to adopt several various innovations simultaneously. Modelling using a multivariate Probit approach allows for increased efficiency in estimation in the case of simultaneity of adoption.

Empirically the model can be expressed as follows:

$$\begin{aligned} I_{i1} &= X'_{ij1}\beta_1 + \varepsilon_{i1} \\ I_{i2} &= X'_{ij2}\beta_2 + \varepsilon_{i2} \\ I_{i3} &= X'_{ij3}\beta_3 + \varepsilon_{i3} \\ I_{i4} &= X'_{ij4}\beta_4 + \varepsilon_{i4} \end{aligned} \qquad (1)$$

Where, I denotes firm index, $I_{i1} = 1$, if the firm introduces a frugal innovation (0 otherwise), $I_{i2} = 1$, if the firm innovates in product (0 otherwise), $I_{i3} = 1$, if the firm innovates in process (0 otherwise), $I_{i4} = 1$, if the firm introduces an environmental innovation (0 otherwise), X'_i is a vector of explanatory variables, β_j is a vector of unknown parameters (j =1, 2, 3, 4), and ε is the error term.

The hypotheses can be tested by running four different independent Probit models by assuming that error terms are mutually exclusive. However, the decision to introduce different innovations may be correlated, thus the elements of error terms might experience stochastic dependence. In this situation, a multivariate Probit model of the following form is used to test the hypothesis:

$$I_{ij} = X'_{ij}\beta_j + \varepsilon_{ij} \quad (2)$$

Where I_{ij}(j=1,…,4) represents the four innovation types where the *ith* firm (i = 1,…, 1000) can be engaged, X'_{ij} is a 1×k vector or unobserved variable that affects this choice decision by the firm, β_j is a k×1 vector of unknown parameters, and ε_{ij} is the unobserved error term. Assuming that the error terms (across j = 1,…, m alternatives) are multivariate and are normally distributed with a mean vector equal to zero, the unknown parameters in Equation (2) are estimated using simulated maximum likelihood. To evaluate the multivariate normal distribution, we use the Geweke-Hajivassiliour-Keane (GHK) smooth recursive conditioning simulator procedure[11] (Train, 2003). In this article, pair-wise correlation of the error terms associated with the firm's adoption decision of innovation behaviour is computed and its significance is tested further to justify, on the one hand, the use of the multivariate Probit model and, on the other hand, to point out the simultaneity and complementarities between various types of innovations.

Because single (*InnoSimp*) and complex (*Innocomp*) innovator behaviours are strongly correlated to the other innovation variables we decided to run two multivariate Probits. A quadrivariate Probit model when analysing four types of innovation (frugal, product, process, and environmental), and a trivariate Probit model in which the firm chooses between frugal, single, and complex innovation strategy.

In Appendix C we give the table of correlation between variables. We note the strong (but expected) correlation between the various types of innovation. We note that the variable RDCA is correlated to many types of innovation. Otherwise the variable *CEengagstrong* has a dense statistical relationship with many endogenous innovation variables.

[11] The estimation is carried out on STATA software according to the Cappellari and Jenkins (2003) procedure.

Section 6. Results and discussion: frugality, types of innovation, environmental change

The empirical results from the multivariate Probit models are presented in Tables 3 and 4. The covariance matrix at the bottom of each table shows that the correlation coefficients of the error terms (Rho_{ij}) are highly significant and the likelihood ratio test on the null hypothesis that Rho_{ij} are jointly equal to zero is significantly rejected. Hence, strong support for the choice of multivariate Probit Model is provided. The significance of the correlation coefficients also argues for *interdependence and simultaneity* between the different strategies of innovation development.

Table 3. Multvariate Probit estimation (1)

	InnoFrug (1)	**InnoPro (2)**	**InnoProced (3)**	**InnoEnv (4)**
RDCA	0.129***	0.289***	0.252***	0.0327
	(0.0349)	(0.0370)	(0.0344)	(0.0545)
VSE	-0.178	-0.544***	-0.577***	-0.230
	(0.149)	(0.152)	(0.141)	(0.205)
SE	0.0916	-0.258*	-0.187	-0.0658
	(0.156)	(0.155)	(0.143)	(0.205)
LE	-0.00439	-0.124	-0.136	0.0392
	(0.263)	(0.276)	(0.239)	(0.338)
CEengagstrong	0.560***	0.0797	0.208**	0.940***
	(0.0918)	(0.0925)	(0.0950)	(0.122)
EnvCertif	0.508***	0.500***	0.458***	0.0406
	(0.112)	(0.107)	(0.104)	(0.153)
BtoB	0.187**	-0.0748	-0.196**	-0.188
	(0.0949)	(0.0959)	(0.0965)	(0.131)
LackInternSkil	0.180*	0.0944	0.0522	-0.231**
	(0.0951)	(0.0895)	(0.0916)	(0.117)
MinChem	-0.174	0.173	0.359	-0.306
	(0.217)	(0.233)	(0.247)	(0.237)
OrgChim	-0.279**	-0.0964	-0.0392	0.0311
	(0.126)	(0.123)	(0.118)	(0.163)
Parachim	-0.329	0.0850	0.115	-0.269
	(0.210)	(0.230)	(0.235)	(0.278)
Others	0.298***	-0.237**	-0.163	0.194
	(0.114)	(0.112)	(0.112)	(0.170)
Constant	-0.246	0.188	-0.165	1.109***
	(0.181)	(0.184)	(0.178)	(0.249)
Observations	1,000	1,000	1,000	1,000
log-likelihood		-1800.886		
Prob > chi2		0.0000		
Rho21		0.506*** (0.045)		
Rho31		0.433*** (0.049)		
Rho41		0.228*** (0.076)		
Rho32		0.746***(0.031)		
Rho42		0.102 (0.077)		
Rho43		0.237***(0.067)		
LR Test :				
H0 : ($\text{Rho}ij$)=0		360.211***		

Table 4. Multvariate Probit estimation (2)

	InnoFrug (1)	InnoSimp (2)	InnoComp (3)
RDCA	0.133***	-0.00976	0.244***
	(0.0355)	(0.0366)	(0.0360)
VSE	-0.157	0.121	-0.580***
	(0.148)	(0.154)	(0.142)
SE	0.110	0.202	-0.262*
	(0.154)	(0.151)	(0.143)
LE	0.000413	0.453*	-0.202
	(0.257)	(0.257)	(0.265)
CEengagstrong	0.571***	-0.202**	0.198**
	(0.0924)	(0.0953)	(0.0922)
EnvCertif	0.493***	-0.121	0.509***
	(0.112)	(0.115)	(0.107)
BtoB	0.191**	0.132	-0.160
	(0.0954)	(0.0979)	(0.0975)
LackInternSkil	0.188*	0.141	-0.00222
	(0.0962)	(0.0961)	(0.0920)
MinChem	-0.168	-0.836***	0.528**
	(0.212)	(0.252)	(0.237)
OrgChim	-0.265**	0.0876	-0.105
	(0.126)	(0.119)	(0.116)
Parachim	-0.339	-0.0187	0.173
	(0.211)	(0.243)	(0.226)
Others	0.324***	-0.00296	-0.257**
	(0.116)	(0.117)	(0.116)
Constant	-0.280	-0.907***	-0.230
	(0.179)	(0.190)	(0.177)
Observations	1,000	1,000	1,000
log-likelihood	-1449.260		
Prob > chi2	0.0000		
Rho21	-0.062 (0.051)		
Rho31	0.460*** (0.051)		
Rho23	-0.843***(0.025)		
LR Test : H0 : (Rhoij)=0	339.267***		

The estimated correlation coefficients between the firms' innovation categories (Table 3) are statistically significant. In particular, the correlations between frugal innovation and product innovation equation (0.506), and frugal innovation and process innovation equation (0.433), suggest that unobservable factors that increase the probability of higher frugal innovation also increase respectively the probability of more product and process innovations. Nevertheless, the coefficient related to process innovation is weaker. As a matter of fact, for the two types of innovation the descriptive statistics and the coefficients estimated are very close. This result is not totally in accordance with the premises of this study that hypothesised a more intense relationship between frugal innovations and product innovations, compared to process innovations (hypothesis 1). From Table 3 another result shows that environmental innovators and frugal innovators are interrelated. The correlation of the coefficient is positive and statistically significant (0.233). This is consistent with our view that supports complementarity between such strategies (hypothesis 3). In Table 4, the most important result is the confirmation of the complementarity between frugal innovation and complex innovation strategy, coherent with respect to our expectation (hypothesis 2). The negative correlation between single innovation and complex innovation (−0.843) is intuitively reasonable. Namely, unobservable factors that increase the probability to be a simple innovator also reduce the probability to be a complex innovation. The two strategies are conflictual by definition. Only two of the correlation coefficients in the results tables (3 and 4) are not significant (product innovation/environmental; frugal innovation/single innovation) which implies first that product innovation is not carried out simultaneously with environmental innovation, and second that frugal innovation is not related to single innovator conduct. For the first, the result may be due to the fact that, in the chemicals industry, the innovation in environmental innovation is mainly done through process innovation and not through product modifications. The second tends to confirm the strategic importance of complex innovation for technological frugality. These findings do not change our result on the interdependence and simultaneity of the various categories of innovation since almost all the coefficients are significant.

We look now at the estimated coefficients related to independent variables. Investing in R&D (here the variable is measured as a proportion of firm turnover) is a driver of innovation in line with what all the literature tells us. One interesting exception is the conduct of the environmental innovator. Environmental innovation is not pulled by R&D activity. The reason might be due to the fact that we retain a definition for this kind of innovation that is larger than a technological innovator; we include organisation or marketing improvements that generate environmental benefits compared to alternatives. Moreover, we have noted that process innovation seems to be the medium of environmental improvements. As a consequence, this type of innovation does not require a high volume of resources invested in research. Single innovation is not related to R&D activity as well. This finding may be linked to the fact that pure process innovators (carrying out a few R&D activities) are included in single innovators by definition. Our estimations show that very small firms (fewer than ten employees) have a lower propensity to achieve FI or other types of innovation (in comparison to larger firms). They meet barriers specific to their size[12]. In general, we find a linkage between firm engagement in CE and its behaviour in terms of innovation. The only exception we have concerns conduct related to product innovation (the coefficient related to CE is weakly significant). It means that investing in CE involves innovating in the processes of production.

Results related to other control variables deliver interesting insights. Getting an environmental certification (variable: *EnvCertif*) is correlated to many innovation strategies with the exception of single innovation. The fact that there is no statistical link between this variable and the occurrence of being an environmental innovator could be considered as unusual at first but it is quite logical once we note that our definition of environmental innovator is to some extent rather poor (only one environmental change among many possibilities). Getting an environmental certification requires more solid competence in ecological issues. As a result, we can think that it implies rich environmental changes in the technologies that the firm masters. Regarding the firm's position with other industrial players the variable related to a BtoB configuration gives mixed results. It has a significant positive effect on the propensity

[12] While this topic is controversial, a large firm can manage a lot of recombination projects in the same time period. They are considered to be more innovative than small firms. As a consequence, a large firm should have a higher probability to innovate frugally than a smaller one. Our estimations do not totally validate this idea.

to innovate frugally. Finally, the lack of internal skills plays a role in the strategy to innovate frugally but not in the other types of innovations. Nevertheless, its coefficient is small and weakly significant. It confirms the analysis built up by Ploeg et al. (2020) and the hypothesis retained by Keupp and Gassmann (2013). It is important to put forward the fact that it has a negative effect on the strategy to implement environmental innovation, establishing a barrier to innovation in that field.

Our perspective, a new perspective with respect to the recent literature, was to look at what type of innovator is the innovator that innovates frugally. From our findings we draw implications that establish our contributions. The idea that the FI is primarily a new product emerges from both the academic and professional literature. Therefore, a frugal innovator would, above all, be a product innovator. Our econometrical work does not wholly support such an idea. We find a significant relation between process innovator and frugal innovator. FI can take the form of process innovation (that is very often less visible than a new product launched on the market). This result gives meaning to the insight that the new frugal product often performs in a frugal way (Brem and Wolfram, 2014; Moore, 2011). In the recent literature, such a process is known as *frugal engineering* (Brem and Wolfram, 2014). As far as theoretical implications are concerned an important finding is that FI is rather related to a complex innovator. The importance of this Schumpeterian type of innovator strategy has been identified very recently (Le Bas and Poussing, 2014; Tavassoli and Karlsson, 2015). Our study confirms the relevance of this taxonomy. It has a deep meaning because frugality is more linked to technological complexity than a single innovator. Of course, many single innovators innovate frugally, but the proportion of complex innovators innovating in product and process is larger (see Table 2). A third result merits a discussion. FI and environmental innovation are linked. This is not surprising. It confirms that FI is basically a particular kind of environmental innovation (Le Bas, 2020). It confirms the view that it is relevant in terms of firm strategy as in terms of public policy to discuss the consequences of FI in the sustainability paradigm.

Conclusion

This paper addressed the issue: What type of innovator is a frugal innovator? The literature that is interested in the characteristics of FI has so far provided very limited insights, both from the theoretical and empirical perspectives on this topic. Our references are built on the Schumpeterian view on innovation based on four main types of innovator: process, product, single, complex. This study establishes a first step aimed at incorporating a wide range of innovation strategies in a frugal innovator empirical setting. A frugal innovator can innovate in its product as in its processes in line with the work by Reinhardt et al. (2018). In this study, we find a clear relationship between FI and other firm strategies in terms of innovation. In general, a firm that innovates frugally is a complex innovator (innovating in product and process) that also carries out improvements in the environment (environmental innovator). Proof that environmental concerns and a frugal approach to innovation are related (Le Bas, 2020; Tiwari and Herstatt, 2020). The more a firm devotes resources to R&D activity the more it increases its propensity to innovate frugally. One important finding: our variable of the lack of internal skill, whose action is controversial as a driver of FI, plays a role in the strategy to innovate frugally but not in the other type of innovations, confirming the scheme of Ploeg et al. (2020). While we have no other benchmarks, however, these findings remain consistent with current analyses of the determinants of innovation (role of R&D, barrier effect of small size). Because it offers information on certain characteristics of frugal innovators, our

work can help the designers of public policies dedicated to innovation who would like to support technological frugality because of its sustainability properties.
As far as limitations are concerned, one specific point deserves attention. A first limitation comes from our methodological approach for measuring the prevalence of each type of innovation. We favoured direct answers to questions (the CIS methodology) rather than the use of objective indicators such as patents. Our data come from the chemicals industry. It might be that technological frugality presents other features in other industries. For instance, a low-tech product in the car industry could provide slightly different insights. With respect to that issue, one fruitful new research direction would be to use the technological sectoral trajectories model by Pavitt (1984). We can assume that there are sectoral patterns of frugal technological change whose basic characteristics and variations would deserve to be investigated.

Our research shows basically the relevance of the link between technological frugality and ecological perspectives as exemplified by numerous pieces of the literature (among many others: Albert, 2019; Winkler et al., 2020; Hossain et al., 2021). For example, a strong firm commitment to the Circular Economy is deemed to be linked to FI and also complex innovator behaviour because the topic is crucial in the context of ecological crisis. New future explorations should be undertaken in this direction. Analysing the complex relations between CE (as a sustainable system of regeneration) and innovation (frugal or not) seems to be a rich perspective in terms of the empirical issues at stake and implications for strategy.

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Appendix A: definition of diverse types of innovation

A technological innovation is a new combination of existing ideas or recombined or updated pieces of knowledge (Fagerberg et al., 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 et al., 2005). The former corresponds to the creation of a new or improved product, whereas process innovation involves changes in the way a product is made (manufactured) without changing its structure (Swann, 2009). Fagerberg et al. (2005) point 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).

Appendix B. Definition of the main innovation variables

Types of innovation (*Variables*)	**Questions Asked of Sampled Firms**
Product Innovation (*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)?
Process Innovation (*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?
Environmental Innovation (InnovEnv)	During the past three years has your company introduced: an environmental innovation which consists of the introduction of an innovation in product (good or service), process, organisation 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 CO2 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

Appendix C. Correlation table

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
(1) InnoFrug	1.000																	
(2) InnoPro	0.365***	1.000																
(3) InnoProced	0.326***	0.606***	1.000															
(4) InnoEnv	0.187***	0.100***	0.127***	1.000														
(5) InnoSimp	0.009	0.217***	-0.282***	-0.034	1.000													
(6) InnoComp	0.342***	0.712***	0.920***	0.127***	-0.446***	1.000												
(7) RDCA	0.157***	0.375***	0.369***	0.057*	-0.021	0.380***	1.000											
(8) VSE	-0.163***	-0.262***	-0.287***	-0.058*	-0.002	-0.274***	-0.336***	1.000										
(9) SE	0.097***	0.103***	0.122***	0.029	0.018	0.105***	0.127***	-0.683***	1.000									
(10) LE	0.053*	0.127***	0.120***	0.023	0.034	0.110***	0.224***	-0.229***	-0.137***	1.000								
(11) CEengagstrong	0.247***	0.064**	0.112***	0.266***	-0.074**	0.119***	0.026	-0.045	-0.002	0.028	1.000							
(12) EnvCertif	0.231***	0.278***	0.301***	0.089***	-0.060*	0.314***	0.291***	-0.292***	0.103***	0.146***	0.254***	1.000						
(13) BtoB	0.085***	-0.056*	-0.085***	-0.021	0.042	-0.088***	-0.145***	-0.056*	0.055*	0.005	0.152***	-0.025	1.000					
14() LackInternSkil	0.033	-0.003	-0.018	-0.093***	0.053*	-0.032	-0.039	0.018	-0.010	-0.028	-0.049	-0.122***	0.109***	1.000				
(15) MinChem	-0.000	0.076**	0.103***	-0.052	-0.079**	0.123***	0.096***	-0.086***	0.035	0.068**	-0.032	0.080**	0.015	0.014	1.000			
(16) OrgChim	-0.059*	0.039	0.036	0.006	0.039	0.022	0.061*	-0.175***	0.125***	0.041	-0.026	0.049	0.041	0.022	-0.103***	1.000		
(17) Parachim	-0.046	0.022	0.022	-0.034	0.008	0.019	0.009	-0.024	0.004	-0.019	0.003	-0.034	0.035	0.039	-0.045	-0.095***	1.000	
(18) Others	0.093***	-0.079**	-0.060*	0.035	-0.001	-0.069**	-0.065**	-0.103***	0.101***	0.001	-0.031	0.005	0.009	-0.069**	-0.112***	-0.233***	-0.103***	1.000

* p<0.10, ** p<0.05, *** p<0.01