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RESOURCE FEEDBACKS FOR CONTINUOUS INNOVATION: THE ARTICULATION OF FIRM, UNIVERSITY, AND GOVERNMENT ROLES

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Abstract:
This paper seeks to advance our understanding, broadly, of innovation dynamics, and specifically, of conditions that favor continuous innovation, including the contribution of governments and universities. Based on a theory of continuous innovation as conditioned by endogenous knowledge and funding feedbacks, and on a theory of conditions that create niches for innovative firms we develop a series of predictions about the conditions and roles needed to support continuous innovation in three types of innovation systems: science coevolution, technology recombination and experience continuity. These predictions are tested on a diversified sample of firms, using measures of managerial perceptions. Results largely support our predictions. In conclusion we propose a typology of roles for each of these cycles and suggest which of them can be best played by universities, governments and firms.

JEL - codes: P19, -, -

Resource feedbacks for continuous innovation: The articulation of firm, university, and government roles

ABSTRACT

This paper seeks to advance our understanding, broadly, of innovation dynamics, and specifically, of conditions that favor continuous innovation, including the contribution of governments and universities. Based on a theory of continuous innovation as conditioned by endogenous knowledge and funding feedbacks, and on a theory of conditions that create niches for innovative firms we develop a series of predictions about the conditions and roles needed to support continuous innovation in three types of innovation systems: science coevolution, technology recombination and experience continuity. These predictions are tested on a diversified sample of firms, using measures of managerial perceptions. Results largely support our predictions. In conclusion we propose a typology of roles for each of these cycles and suggest which of them can be best played by universities, governments and firms.

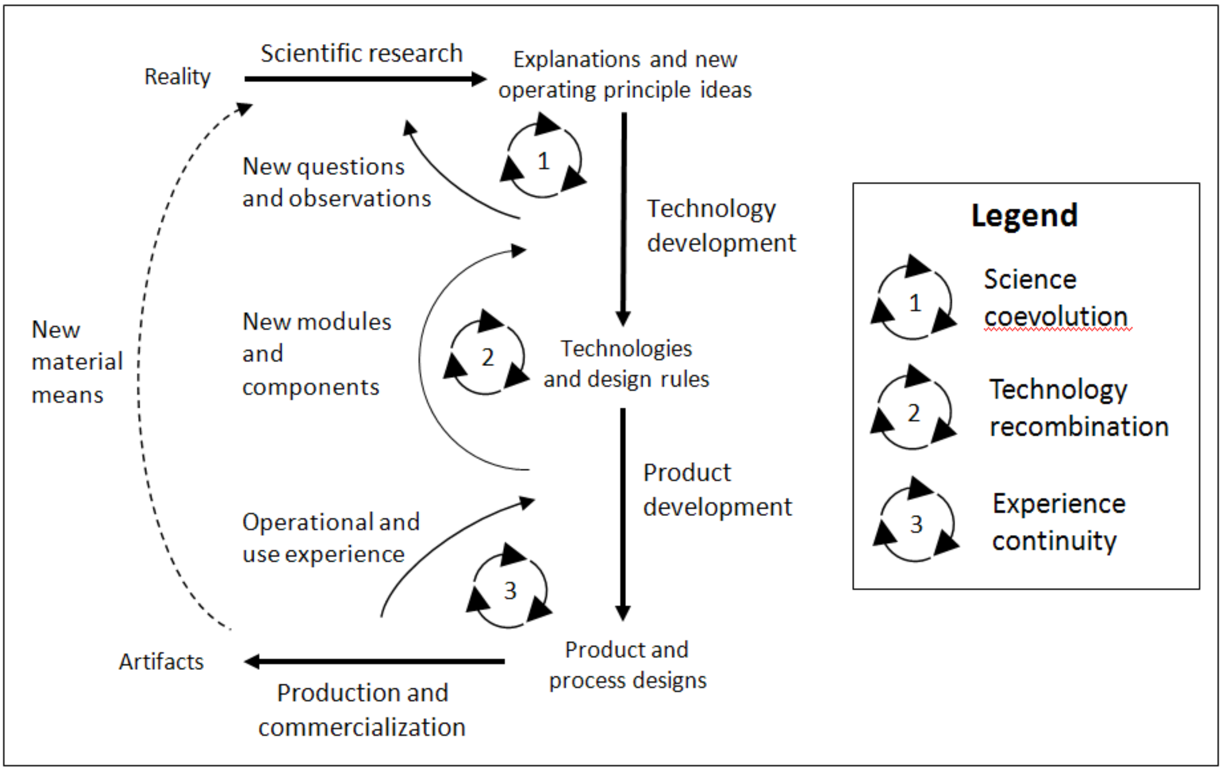
1. Introduction and Synopsis

This paper seeks to advance our understanding, broadly, of innovation dynamics, and specifically, of conditions that favor continuous innovation. Recent advances suggest that continuous innovation requires mutual support among universities, governments, and firms, but different authors attribute the key role to different elements of this triad, and propose different modes of interaction among them (Nelson 1993, Etzkowitz and Leydesdorff 2000). Resolving this debate calls, in our view, for a better understanding of the different activities involved in innovation, of the collaborative and protective relations among the actors involved in these activities, and of the role of resource flows in shaping these relations. For example, one disagreement over the role of universities concerns the need to encourage the patenting of research results. While this activity stimulates, and draws more resources to, the production of knowledge relevant for innovation, it may divert efforts from basic research and hamper the flow of knowledge to industry (Henderson et al. 1998, Rosenberg and Nelson 1994). Such debates can be resolved or, at least, advanced by understanding the different roles of knowledge in innovation and how the protective barriers stimulate or block its application.

In this paper we build on Floricel and Dougherty's (2007) hypothesis that continuous innovation relies on endogenous feedback cycles in innovation systems, which concurrently reproduce two key resources for innovation: knowledge and funding. We start with the more or less traditional division of innovation activities in four categories: research, technology development, product development, and production-commercialization, and suggest that each of them produces respectively new explanations and ideas for new technological principles, new technologies and design rules, new product and parts, and new operational and use experience. Figure 1 shows the knowledge feedbacks that can emerge among these activities. Floricel and Dougherty (2007) argue that, in several sectors, currently and historically, these knowledge feedbacks have been paralleled by funding feedbacks, and resulted in three types of re-production cycles that support continuous innovation—science-coevolution, technology-recombination, and experience-continuity. Each is built around distinct activities and roles and has different knowledge and funding dynamics.

We also draw upon Floricel and Miller's (2003, see also Miller and Floricel 2007: 14-18) study of contextual conditions that enable the emergence of a diversity "games of innovation" with stable dynamics, practices and value creation emphases. They suggest that each "game" finds a niche that balances three innovation factors: knowledge dynamism, structuring potential and demand specificity. We deduce from their contribution that the structuring potential, meaning the speed and selectivity with which systems build barriers around innovation initiatives is a key factor in their ability to sustain continuous innovation. Such niches are needed to protect innovating firms that attract, nurture and pass along resources in each renewal cycle. We also link the diversity of niches to the distinct requirements that each type of cycle poses for participating firms, function of the particular nature of its knowledge and funding renewal. Moreover, we argue that the higher the dynamism of relevant knowledge, the stronger is the structuring potential needed to ensure the continuity of innovation. Together, our understanding of resource dynamics and protective requirements in each cycle enables us to identify optimal roles for universities, governments and firms in each cycle, and propose a differentiated typology of roles.

Figure 1 Innovation activities, knowledge feedbacks and renewal cycles



The implications of these theoretical developments are explored in the present research by using the results of a worldwide survey of firms. The survey (see Miller and Floricel 2007b for more details) measured managers' perceptions regarding the three innovation factors discussed above in their respective sectors, their firm's value creation emphasis in innovation, and their firm's relations to other players such as governments and universities. Results were analyzed both at the level of individual firms and by grouping firms into 4-digit NAICS sectors. Overall, results tend to support the theoretical predictions. For example, a mapping of sectors on these three innovation factors suggests that a stronger structuring potential is needed to balance the disruptive effect of higher knowledge dynamism. Moreover subgroups of firms that belong to the same feedback cycle tend to concentrate in proximate but slightly different niche spaces. The assessment firms make of their relations with governments and universities tends to support our argument about the distinct ways in which these players articulate with the three types of feedback cycles. These results enable us to make, in conclusion, several contributions to the debate about the complementary roles of university, governments and firms in continuous innovation.

2. Theoretical background

One of the key theoretical tenets of the research on innovation is a systemic view. In this view, observable social phenomena are not an ever renewed (ad hoc) combination of free self-centered actions by lower level actors (Bunge 1996). Instead, actions are conditioned by a set of preexisting relations among actors, which channel actions into specific patterns, some of which also reproduce the relations, and hence, the system. The configuration of relations cannot be explained by the sum of lower level interests and actions at a given moment; it emerges from a historic evolution process (North 1990). The innovation systems literature focuses on the role of stable relations that emerge in nations and regions with respect to the government support for education, science and innovation, to the involvement of universities in innovation activities, to the support of financial institutions for innovation, as well as between firms (Freeman 1988, Porter 1990, Lundvall 1992). Differences in such relations were used to explain differences in innovation vitality and economic success, as well as specialization, across nations and regions. More recently, specific patterns of relations were identified across sectors, defined based either on market, technology, or combined criteria (Malerba 2002, Carlsson et al. 2002). The configuration of relations has often been related to the specifics of value creation, technologies and artifacts in the given sector (Pavitt 1984; Miller et al. 1995).

The systemic view also holds significant promise for improving our understanding of innovation dynamics. Most explicit models of innovation dynamics are still variants, or partial criticisms, of the lifecycle view (see Klepper 1997 for a review). Floricel and Dougherty (2007) argue that these models include some implicit systemic assumptions, which are not fully justified. Models depict radical innovations as a disturbance for sectoral systems; quickly damped by processes that return the systems to a state of minimal innovation. But these processes assume, in turn, a series of limiting technological and market conditions, as well as relations that translate these conditions into actions which divert resources away from innovation. Floricel and Dougherty (2007) further suggest that observations of several sectors do not justify such restrictive assumptions; these sectors simply do not follow the predicted life cycle pattern (see also Henderson 1995). In fact, life cycle assumptions may reflect a specific historic state of research, government and financial institutions, as well as a specific understanding of technology, and of organizing industries and businesses. Under different conditions, sectoral systems will more likely reproduce a state of continuous innovation.

2.1 Resource renewal cycles

To explain such patterns, Floricel and Dougherty (2007) advance the hypothesis that systems with continuous innovation emerge and thrive in the presence of two mutually supporting feedback cycles, which reproduce, respectively, the knowledge and funding needed for innovation. A knowledge feedback cycle means that some innovation activities also produce a lot of knowledge, such as theories, data, ideas, learning etc., which is an input for, or stimulates, the production of new knowledge useful for innovation. A funding feedback cycle means that part of the value produced by innovation activities can be captured and reinvested in innovation, or can at least induce expectations that attract new resource inflows. Floricel and Dougherty (2007) identify three types of knowledge feedback cycle, which, together with the corresponding funding cycles, support three types of innovation systems with continuous innovation. As detailed in Table 1, these three systems are termed science-coevolution, technology-recombination, and experience-continuity systems.

Science-coevolution systems are based on feedback between research activities that produce new explanations of natural phenomena, and technology development activities that attempt to transform the latest insights into new operating principles (Polanyi 1966, Vincenti 1990). In their course, technology development activities produce new findings, issues, and ideas that can be fed back to scientific research activities. This feedback can continue indefinitely if the natural phenomena of interest are very complex, such as those addressed by the biotechnology and pharmaceutical industries. The corresponding funding feedback occurs as the value created by the technology development activities, mostly in the form of IP rights and success expectations but also eventually as final products and services, triggers new inflows of anticipatory funds into research and technology development activities. This kind of feedback can also continue indefinitely if investors see opportunities to capture some of the value they create, even at the end of a long development process. One requirement stemming from the condition of matching the dynamism of knowledge production and of funding is that benefiting from these opportunities should not require investment concentration in a given area, at the expense of opportunities stemming from new and unrelated technological principles. In other words, investment has to branch out the same way knowledge does. Otherwise knowledge renewal is eventually disrupted, leading to investment opportunity exhaustion.

Technology-recombination systems are based on feedback between technology development activities that produce new architectural combinations out of the latest technologies and modules, and product development activities, which transform these combinations into new products and modules. In doing so, product development activities also make available new candidates for recombination. The feedback can continue indefinitely if the technological systems of interest are very complex, such as telecommunications, Internet, computers, software, MIS and other digital systems. The funding feedback is based on the value created by the new technologies and products, which holds out the expectation of a relatively fast return from investment in innovation. In this case, to enable the reproduction of innovation, niches only need to protect anticipated returns for a shorter period of time, and, while a diverse novelty is sought, the "lateral jumps" stay closer that in the previous cycle, as most innovations are related to already existing technologies.

Finally, experience-based systems are based on feedback between product development activities that use existing technologies, architectures and design rules to develop improved product and process forms, and production and operation activities, as well as product marketing and use that produce new experience-based learning. This learning can inspire new product forms or marginally improve existing ones. The feedback can continue indefinitely if the artifacts that are created, either for products or for production and operation processes, are complex, as is the case in sectors like automobiles, electricity, petrochemicals, aerospace etc. The funding feedback involves the value obtained by selling products, and a niche that enables firms to retain and reinvest part of these proceeds in closely related innovation. This ensures the continuity of experience that is a condition for the accumulation of learning.

In sum, our systemic argument is that certain relations between kinds of innovation activities, and between entities that perform them, ensure a continuous flow of opportunities and resources for innovation activities of the same kinds. Table 1 conveys the convergence between the dynamism of the knowledge feedback cycle and that of the funding feedback cycle in the three types of systems. In addition, these relations tend to persist because they grow stronger as they become taken for granted (Bogner and Barr 2000; Garud and Karnøe 2003). When this happens, rather than following a life cycle, innovation systems tend to persist in what looks like one of the earlier stages of a life cycle.

Insert Table 1 aboout here

2.2. Conditions for innovation existence.

In turn, Miller and Floricel (2004) observed that some firms, indeed entire strategic groups or even sectors, seem to persistently emphasize particular ways of creating value, different from those of other groups. Namely, they emphasize to a different extent the following dimensions of value creation: (i) transformation of new science into technologies ("productizing"); (ii) the compatibility with other products and systems ("alignment"); (iii) the quality, reliability and cost of products ("engineering"); and (iv) the detailed understanding of customer needs to anticipate and solve their problems ("matching"). Floricel and Miller (2003) realized that persistent differences among these groups, which they dubbed "games of innovation," must be due to the particular conditions for innovation with which these groups are regularly faced. The particular emphasis is, in fact, a way of surviving in these conditions, by creating niches that protect firms long enough to enable them to attract funds and develop organizational capabilities, technologies and innovative products, as needed. They also realized that these niches also have to ensure sufficient organizational entry and demise in order to avoid blocking innovation in highly dynamic conditions (Thomas 1996).

Floricel and Miller (2003) captured these contradictory contextual demands by three dimensions— knowledge dynamism, structuring potential and demand specificity—which map three essential ingredients of any innovation, namely technical opportunity, investment, and customer demand. Knowledge dynamism creates new opportunities for innovation, and hence new entries. But is also a destabilizing factor for incumbent firms and current innovation projects, because it creates alternative and substitute initiatives that can drive away practitioner energy, funding and eventually sales. This factor can be linked to the resource renewal cycles by using the latter to explain the persistence of knowledge dynamism. High knowledge dynamism corresponds to an innovation system attached to an effervescent field of science via a science-coevolution resource renewal cycle (Floricel and Dougherty 2007). Average knowledge dynamism, would correspond to a system that produces internally a significant amount of new technologies based on a vibrant technology recombination cycle. Low knowledge dynamism would correspond to a system that produces a significant amount of learning around existing artifacts and processes via an experience-continuity cycle.

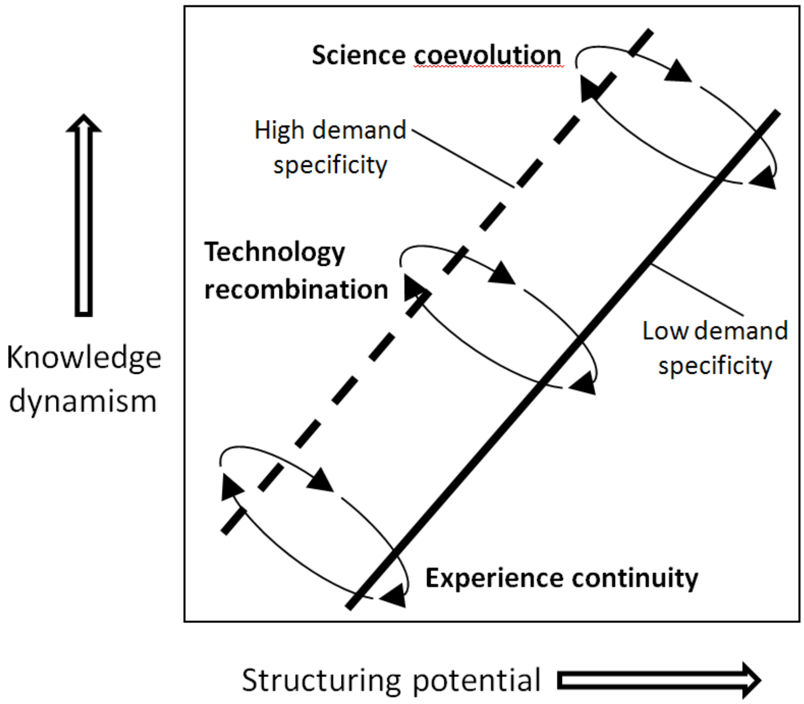
In turn, structuring potential captures the speed with which the system creates protective barriers around an innovation initiative, as well as the selectivity and solidity of these barriers. The structuring potential is a stabilizing factor, because it gives a potential advantage to current innovation projects and incumbent firms in the face of new initiatives. Here again, the degrees of structuring can be linked to the requirements of the resource renewal cycles. High structuring potential consists of institutional barriers such as safety and health regulation and intellectual property protection, which, for some types of technologies and products can exclude competition for significant periods of time (Teece 1986). These barriers are technology- and product-neutral, in the sense that they can be applied to any new technological idea, which enables the bold lateral jumps that were proposed as a condition for funding renewal in the science-coevolution cycle. Average structuring potential is created for certain products and systems by technical compatibility requirements and related network effects, which trigger highly nonlinear advantage building processes leading to rival exclusion (Arthur 1989; Shapiro and Varian 1999). This structuring potential is related to current technologies and products, enabling only related lateral jumps, which were proposed as a condition for funding renewal in the technology recombination cycle (Podolny 1996). A low structuring potential is created by the economic logics present in certain products and production and operation processes, such as economies of scale and scope, and learning effects, which work out at a slower pace, conditioned by the rhythms of large capital investment and cumulative production of complex products, and create a milder advantage, still leaving room for entry and rivalry (Porter 1980). Because this structuring potential is related to current assets and operations, it enables only incremental deviations from current technologies and products, like the one required for reinvesting funds in the experience-continuity cycle.

Finally, demand specificity is related to the fact that some groups of firms target customers which have highly specific, advanced and special needs (von Hippel 1986). Many, but not all, of these customers are in industrial markets. This is an additional stabilizing factor, related to the fact that supplier-customer dyads can eventually develop a bilateral quasi-monopoly via investment in partner-specific specific capabilities and assets (Williamson 1986). The presence of high demand specificity enables both additional knowledge renewal, as partners learn from each other new needs and respectively new technical possibilities, and additional resource renewal, as clients support innovation by suppliers and receive in turn the possibility to increase their own returns. Hence, demand specificity can protect and help fund groups of firms that venture in domains with higher levels of knowledge dynamism without the corresponding structuring potential.

2.3 Hypotheses about roles

Combining insights from the contributions by Floricel and Dougherty (2007) and Floricel and Miller (2003) produces the configuration depicted in Figure 2. The continuous diagonal traces the areas (niches) in the knowledge dynamism vs. structuring potential space where groups of innovating firms targeting low demand specificity customers are most likely to be found. In turn, the interrupted diagonal traces the area where groups of firms targeting customers with high demand specificity are likely to be found. The circular arrows suggest the areas (niches) where groups of firms belonging to one of the three types of cycles would concentrate. For each cycle, one group of firms (or a few groups) will be on the low demand specificity diagonal, and will play the role of resource renewal anchor for another group (or a few) on the high demand specificity diagonal.

Figure 2 Expected firm concentrations in the condition space



The reasons for the diagonal concentration is that, in conditions of high knowledge dynamism, like in the case of the science-coevolution cycle, the main problem is the disruption caused by the continuous inflow of ideas for new technological principles, which affects the flow of funds for current development projects by destabilizing the expectations of fund providers as well as clients. Therefore, innovation persistence in cycles with higher knowledge dynamism requires stronger niches, which would protect firms long enough from rival innovations. As a consequence, innovation will thrive only in the presence of a higher structuring potential. Firms (groups, sub-sectors) for which the structuring potential is not strong enough for the knowledge dynamism they face will compensate by focusing on applications for clients with higher demand specificity. However, this is probably not sufficient for firms in the top left corner, in which profitable innovation cannot exist. On the other hand, in condition of low knowledge dynamism, the absence of disruptions caused by new knowledge means that a high structuring potential is likely to produce innovation paralysis. Thus, firms in the lower right corner of Figure 2 feel protected and have few reasons to take the risks required to invest in innovation. When knowledge dynamism is low, innovation thrives in contexts with low structuring potential, such as the lower left corner. Moreover, to get more protection, when the structuring potential is very low some innovating firms will focus on applications for clients with high demand specificity and benefiting from a somewhat stronger structuring potential.

Concretely, we expect to observe a concentration of innovating firms along the diagonal. A certain number of firms will also appear below the diagonal, as the protection provided by the high structuring potential will enable them to survive. However, these firms will have a lower innovative performance than firms that are closer to the diagonal. We also expect firms that produce very specialized tools, materials, ingredients, and systems to concentrate to the left of the firms that produce generic or mass-market products, for the same level of dynamism (or above, for the same structuring potential).

Regarding the firms and sub-sectors belonging to different cycles, we expect to have the sectors mentioned above as belonging to each of the three cycles to concentrate in the corresponding areas of Figure 2. Namely, we expect firms in the pharmaceutical and scientific research services sectors, which we designate respectively, using a language inspired by Miller and Floricel (2007) as belonging to science runners and research toolmaker games of innovation, to concentrate in the top right corner. Moreover, we expect research toolmakers to have higher demand specificity and be positioned, on average, to the left or above science runners in Figure 2. We also expect firms in these games to emphasize value production by productizing the latest scientific knowledge, but research toolmakers to have a higher emphasis on matching user needs. Both sectors will also attach higher importance to external knowledge inflows and develop stronger relation with universities and the scientific community than the rest. To perform the unrelated lateral investment jumps discussed above, these firms will also rely more on financial partners that are able to skim funds from a number of sectors and concentrate some of this funding on specific applications unrelated to these sectors. We call this funding role "gatherer-benefactor", which in the current institutional macrostructure is performed not by public markets, but primarily by governments and to a lesser extent by private foundations and wealthy individuals. Hence these sectors will see higher inflows of government funding for innovation than the rest.

Firms in the technology-recombination cycle will concentrate in the center of Figure 2, in areas with average knowledge dynamism and average structuring potential. These firms will belong essentially to two games, architecture navigators, which include semiconductors, computers, communication equipment, and generic software publishing sectors, and system integrators, which include, the information systems design sector. Firms in the system integrator sector will be found, on average, to the left or above the firms in the architecture navigator sectors in Figure 2, and will face customers with higher demand specificity. Firms in both games will create value by aligning their products with dominant standards, but firms in the system integrator game will also emphasize the close matching of user needs. Because, knowledge feedback in this cycle relies mainly on recombining the latest technologies produced by other firms, we also expect firms in these games their relations with other firms as well as with industry associations and standardization bodies. With respect to funding renewal, to perform the related lateral jump mentioned above, firms will need investors that are able to use the gains made on some projects to invest in new yet related technologies. We call these players "leverage-venturers." Because their role is played by venture capital firms in the current institutional structure, we expect firms in this cycle to receive on average more funds from venture capitalists than firms in the other cycles, except perhaps for firms in the science-coevolution cycle, in which venture capitalists may take the relay from gatherer-benefactors.

Finally, firms in the experience-based cycle will concentrate in the lower-left corner of Figure 2, because they face lower knowledge dynamism and lower structuring potential. These firms will include two main groups, each including several games. The low customer specificity group, will include the games of asset optimizer (mining, electric power, basic chemicals, pulp and paper, iron and steel, alumina and aluminum, construction), experience marketer (motor vehicles, machinery, agricultural and construction machinery, ship and boat building), hasty newsmaker (food, soap and detergent, clothing), and safe traveler (medical equipment, aerospace products and parts). The high customer specificity group will include the games of tandem learner (converted paper, resin and rubber, industrial machinery, metalworking machinery, motor vehicle parts), niche advisor (other chemical products, forging and stamping, coating and heat treating, navigation and measurement equipment, architectural and engineering services, management and technical consulting services), and program explorer (aerospace for military purposes). This group will be situated on average to the left or higher in the space of Figure 2. Firms in this group will put a higher emphasis on matching customer needs. Also, overall, firms in the experience cycle will put more emphasis on engineering products with high quality and reliability and low cost. With respect to knowledge renewal all firms in this group will rely on internal sources of learning, universities and public labs would undertake some specialized research tasks on their behalf but will not be a significant source of product ideas. These firms will also finance innovation mostly by allocating revenues internally; they will play a role that we call stingy investor; gatherer-benefactors and leverage-venturers will play a lesser role in this cycle.

3. Methods

The empirical investigation of the theory presented above is exploratory. Hypotheses were tested using psychometric measures included in a broader survey of innovation practices (see Floricel and Miller 2007 for a detailed explanation of the goals and methods used in the survey).

Sample. The survey obtained responses from 793 firms in a variety of sectors and on four continents, with a response rate estimated at 25%. From these, 512 firms provided enough identification information to enable the assignment of a sector code (see below). The sample was then reduced to 422 firms by the elimination of codes with less than 5 cases and the elimination of 4 codes relating to banking, financial and insurances sectors, for which we felt that our theory did not provide sufficient explanation. The final sample included 422 organizations.

Measures. Psychometric questionnaires are appropriate as an initial exploratory measure of innovation conditions and of relations with other participants. Each theoretical dimension was measured by two or three items using 7-point Likert-type scales. The survey instrument was built in three iterations. The first iteration was based on 73 qualitative interviews and produces a first instrument, which was tested on 75 firms. The results produced interesting insights but also many new issues. In the second iteration, based on a revised theoretical framework, more than 100 interviews, a brainstorming session involving five researchers, and comments by several other researchers and by practitioners led to the development of a pre-test instrument. This instrument was tested on 133 firms. Analyses of averages, variance, and reliability, and exploratory factorial analyses, led to modification or replacement for about 20% of items. The result is the final version of the instrument, which includes the measures used in this paper. The particular measures used in the following analyses are described and justified in the Appendix 1.

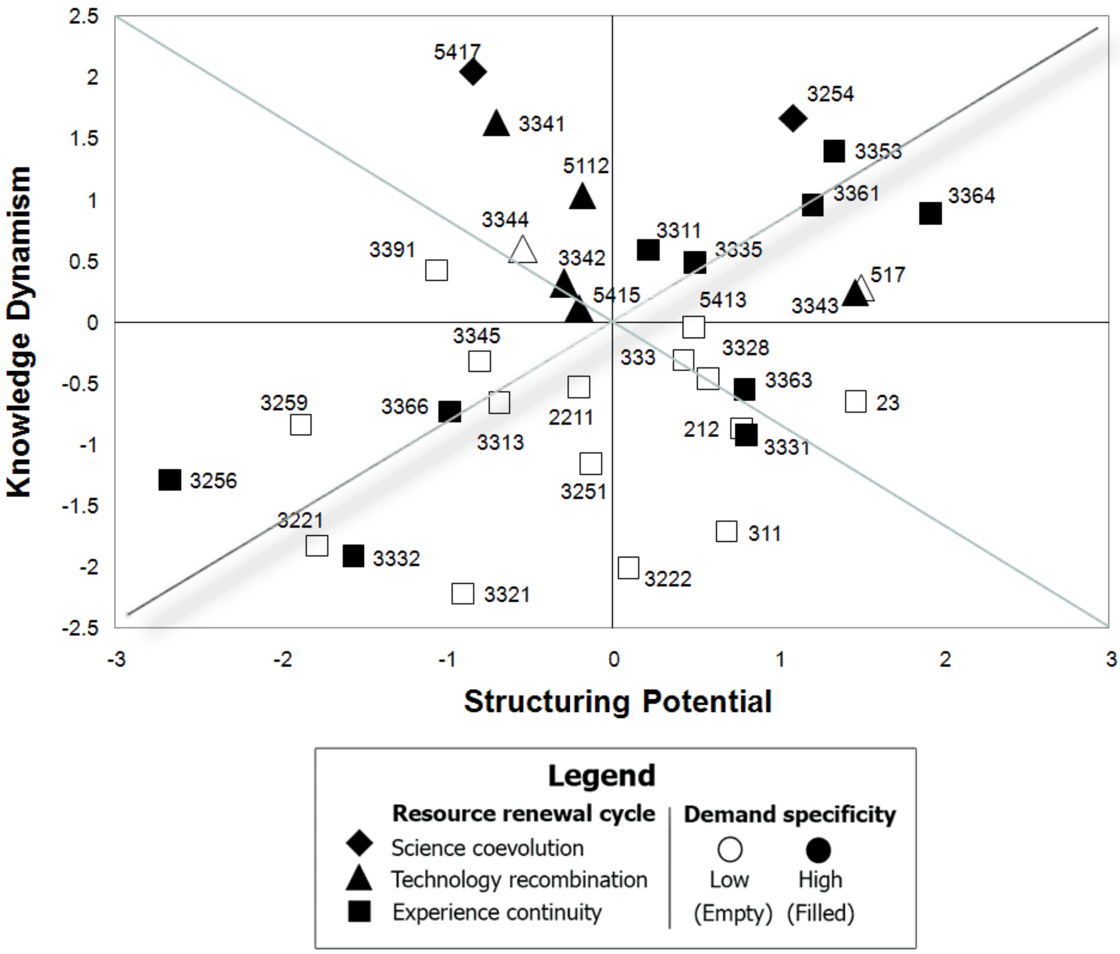
Sector assignment. A doctoral student who is not part of the team that wrote this paper classified firms into sectors using 4-digit codes from the North American Industry Classification System (NAICS). The assignment was based solely on the self-reported sector of activity and on secondary data about the firms obtained, for example, from their Web sites. Each sector was then assigned to a resource renewal cycle (science coevolution, technology recombination, and experience continuity). The classification was then reviewed by the first author, also based on secondary data only. No answers to the survey questions were used for the classification.

4. Analyses and Results

4.1 Patterning of Firm Types in relation to Resource Renewal Cycle Variables

The first analyses of data examine whether respondents in our sample described their sector's dynamism, structuring potential and demand specificity in the ways predicted by the theory depicted in Figure 2. Recall that the firms were classified *a priori* (and independently of the survey data) in terms of which cycle they operated within as well as their industry sector. Although the 422 firms in the sample make it impractical to plot the results at the firm level, a plot of sector means was produced as Figure 3. As the legend indicates, the resource renewal cycle associated with each sector, *a priori*, is symbolized by a diamond, triangle, or square. The correspondence of code numbers to descriptive labels is presented in Appendix B.

Figure 3. Sector averages in the knowledge-dynamism and structuring potential space



Based on the theory, science coevolution firms (whose sector means are shown as diamonds in the figure) were expected to show generally high values on *both* knowledge dynamism and structuring potential; technology recombination firms (triangles), intermediate values on both; and experience continuity firms (squares), low on both. As a formal test of these predictions, the values in the firm-level data for knowledge dynamism and structuring potential were conceived as specifying firms' locations in the two-dimensional space depicted in Figure 3. Jointly high values occur toward the top right corner of the space; jointly low, toward the lower left; and jointly intermediate, toward the middle. Thus one way to produce a single score to represent a firm's position along a continuum from low/low to high/high is to score firms in relation to the corresponding diagonal in Figure 3 (the diagonal that casts a shadow in the figure). This scoring was accomplished by geometric projection from the firm's position in two dimensions onto the single dimension defined by the shadowed diagonal. (The method of projection was identical to that used, for example, in factor analysis when axes are rotated.) The resulting score was the length of the vector from the origin (central point in the figure) to the point of projection onto the diagonal. Negative scores were assigned exclusively to firms that were to the left and below the other, non-shadowed diagonal.

Table 2. Average Positions of Types of Firms along the Low/low – High/high Continuum

Type of cycle	Mean distance from origin	Standard deviation	N of cases
Science coevolution	1.68	2.34	32
Technology recombination	0.27	2.51	121
Experience continuity	-0.31	2.64	244

The findings supported the predictions. Table 2 shows the resulting mean distances from the origin along the key diagonal. Science coevolution firms, on average, are located more than halfway up (M = 1.68) the shadowed diagonal toward the high-high corner. Technology recombination firms are not quite in the center of the space, but they do show the predicted, intermediate position (M = 0.27) among the three kinds of firms. Experience continuity firms, on average, are located in low, low quadrant (M = -0.31), also as predicted.

Moreover, these positional differences among the three kinds of firms were statistically significant. A one-way analysis of variance (ANOVA) yielded $F(2, 394) = 9.14$, $p < .001$. Each of the pairwise comparisons among these groups also yielded statistically significant t-ratios ($t(151) = 2.86$, $p = .005$; $t(274) = 4.04$, $p < .001$; $t(363) = 2.00$, $p = .046$). Thus the firms in each group had distinctive positions in line with the theory.

Secondary to the positioning of firms in relation to knowledge dynamism and structuring potential, there is a potential association with demand specificity. The theory depicted in Figure 2 predicts that firms with high demand specificity will tend to be located toward the *upper left* of the figure, and firms with low demand specificity, toward the *lower right*. This prediction may be tested formally using information immediately accessible in Figure 3. When above average demand specificity was reported by firms in a sector, their symbol was filled in (darkened); the remaining firms have unfilled symbols. (Note that this feature of the symbols corresponds with obtained survey data, not *a priori* prediction based on other information.) According to the theory, darker symbols should predominate above the shadowed diagonal of Figure 3, with the lighter ones below. However, some points lie on that diagonal and are difficult to classify when the diagonal is in exactly the position shown in the figure. By shifting the diagonal slightly downward (leaving 3221 and 2211 below the diagonal but placing 3313 above it), the diagonal cuts cleanly through the space and exactly 17 symbols lie on each side of it. This division yields the cross-tabulation in Table 4.

Table 4. Predicted and Observed Positions of Sectors in relation to Demand Specificity

Predicted Position	Observed Position		
	Above	Below	Total
Above	12	5	17
Below	5	12	17

The association in the table was found to be statistically significant by Pearson's chi-square test ($\chi^2 = 5.77$, $p = .016$), again confirming the hypothesis and supporting the theory depicted in Figure 2.

4.2 System (cycle) level analyses

It was suggested earlier that continuous innovation requires mutual support between the universities, governments, and firms. However, different authors attribute the key role to different elements of this triad, and propose different modes of interaction between them. One influence was related to their participating in funding renewal across the three cycles. Responses were made on a 7-point Likert scale, with 1 corresponding to "Not at all important" and 7 to "Extremely important" preceded by the title "Innovation enabling role" and the question "Importance of role." The two items used in this analysis are presented in Table A4 (in the Appendix 1). Table 5 shows the results of these comparisons. Near the bottom of the table, there appear F-ratios that test differences among cycle types collectively. Further, subscripts next to the mean tables in the table tell which groups differ from each other by TUKEY's test. Means *not* sharing a subscript differ significantly (within columns) at $p < 0.05$. As predicted firms in the science-coevolution cycle seem to perceive on average more government support for their sector, significantly more than firms in the experience-continuity cycle. Likewise, firms in the technology recombination cycle perceive on average, more venture capital inflows in their sector.

Table 5. Differences in the importance of funding roles between governments

Type of Cycle	N	Resource Inflows	
		Government Support	Venture Capital
Science coevolution	32	4.16_{a}	3.47_{ab}
Technology recombination	125	3.62_{ab}	3.77_{a}
Experience continuity	248	3.34_{b}	2.98_{b}
F (2, 402)		4.27*	11.95***
MSe		2.60	2.20

Note. **p* < .05 ***p* < .01 ****p* < .001

Another influence on the role played by these three actors might be in the knowledge renewal cycle. Based on this line of thought we proposed that the role of universities, government agencies and other firms will differ based on the prevalent knowledge cycle occupied by the firm. To explore these propositions we used a portion of the survey that concerned innovation enabling roles played by various network partners. Responses were made on a 7-point Likert scale, with 1 corresponding to "Not at all important" and 7 to "Extremely important" preceded by the title "Innovation enabling role" and the question "Importance of role." Organizations first indicated the importance of a particular enabling role such as "Helps learns about new technology" or "Provides business advice." Ten separate enabling roles were surveyed (see Appendix 1, Table A.5). Organizations then indicated which network partners provided this support. Responses were coded as 1 when a network partner was indicated. To analyze these data we computed a score based on the importance of the particular enabling role multiplied by whether or not the organization indicated that this role was provided by a particular network partner. This score captures both whether or not a network partner is involved in an enabling role and the importance of this role to the organization. A score for each network partner was then computed based on the mean of this score across the ten enabling roles resulting in three composite scores representing the importance played by the network partners (Government, Universities, and Other firms) across all ten enabling roles surveyed. Then we tested whether the means of these scores differed based on the knowledge cycle of the organization. Results presented in Table 6 indicate that overall organizations in different knowledge cycles did indicate that different network partners were important. Near the bottom of the table, there appear F-ratios that test differences among cycle types collectively. Further, subscripts next to the mean tables in the table tell which groups differ from each other by TUKEY's test. Means *not* sharing a subscript differ significantly (within columns) at $p < 0.05$. In particular, firms in the science-coevolution cycle indicated that they rely, on average, significantly more that other groups on governments and universities, while firms in the technology-recombination cycle relied more on other firms than the other two groups, significantly more than firms in the experience-based group. By implication, the latter, seem to rely more on internal resources.

Table 6. Extent of Performance of Innovation Enabling Roles by Three Players for Three Cycle Types

Type of Cycle		Role Players		
	N	Government	Universities	Other Firms
Science coevolution	34	1.86_{a}	1.64_{a}	1.75_{ab}
Technology recombination	122	1.18_{b}	0.92_{b}	1.97_{a}
Experience continuity	245	1.37_{b}	1.03_{b}	1.36_{b}
F (2, 376)		3.36*	4.82**	7.14**
MSe		1.55	1.22	2.05

Note. *$p < .05$ **$p < .01$ ***$p < .001$

We also predicted that firms in the science coevolution cycle will emphasize, relatively, productizing academic research, while firms in the technology recombination cycle will emphasize aligning with other products and systems and firms in the experience-based cycle will emphasize engineering (as defined in section 2). We made no specific prediction regarding creating value by better matching user needs with respect to cycles, but predicted that firms in high demand specificity games will put more emphasis on this aspect of value creation. The four value creation dimensions were measured using the items specified in Table A6 (in the Appendix 1) and a principal component analysis. The first series of results involved a comparison of averages between cycles on these four dimensions. The results, presented in Table 7, support out predictions that firms in the science-coevolution cycle would emphasize productizing more than others, that firms in the technology-recombination cycle will emphasize aligning more, and firms in the experience continuity cycle will emphasize engineering more. These differences are statistically significant. There was also a significant difference, not anticipated, in the sense that firms in the technology recombination cycle also emphasized more matching user needs.

Table 7. Emphases in Value Creation Capabilities

	N	Productizing	Aligning	Engineering	Matching
Science coevolution	34	0.89_{a}	-0.14_{a}	-0.10_{ab}	-0.17_{a}
Technology recombination	122	-0.13_{b}	0.44_{b}	-0.26_{a}	0.30_{b}
Experience continuity	245	0.04_{b}	-0.19_{a}	0.17_{b}	-0.19_{a}
F (2, 398)		15.20***	18.60***	9.20***	10.50***
MSe		0.91	0.89	0.84	0.97

Note. $^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$

With respect to the matching dimension, we also compared groups with high and low demand specificity within each cycle. Results presented in Table 8 show that, as predicted, firms in sector with high demand specificity in the science-cycle seem to emphasize matching more that firms in the same cycle with low demand specificity. This difference was statistically significant. However, for the other two groups, the differences were not significant, and, in the case of firms in the technology recombination cycle the difference had the opposite sign.

Table 8. Emphases in Value Creation Capabilities

Cycle	Demand	N	Matching	Aligning	Engineering	Productizing
Science	low	25	$-.36_{a}$	$-.27_{a}$	$-.04_{a}$	1.02_{a}
Science	high	9	$.36_{b}$	$.22_{ab}$	$-.24_{a}$	$.52_{ab}$
Technology	low	74	$.36_{b}$	$.32_{ab}$	$-.18_{a}$	$.04_{bc}$
Technology	high	48	$.21_{ab}$	$.61_{b}$	$-.38_{a}$	$-.37_{c}$
Experience	low	112	$-.31_{ab}$	$-.21_{a}$	$.13_{a}$	$.10_{bc}$
Experience	high	133	$-.09_{ab}$	$-.18_{a}$	$.21_{a}$	$.00_{bc}$
Cycle Main Effect	F (2,348)		9.22***	19.56***	9.72***	9.59***
Demand Main Effect	F (1,348)		$3.18^{\dagger}$	3.79*	0.62	5.17*
Interaction Effect	F (2,348)		$2.58^{\dagger}$	1.19	1.10	1.35
	MSe		0.95	0.88	0.84	0.89

Note. $^{\dagger}p < .10$ $*p < .05$ $**p < .01$ $***p < .001$

5. Discussion and conclusions

The results presented above appear provide some support for the hypotheses advanced in this paper, namely that systems with continuous innovation rely on differentiated resource feedback cycles, and that players such as firms, universities and governments choose niches that align with these knowledge and funding logics of these feedback cycles. This support is provided by the clustering of firms in related sectors that could be involved in the same cycle in condition areas that are proximate, by the fact that occupy slightly distinct and complementary niches, and by the type of relations that they tend to develop with governments, universities, financial institutions and other firms. This enables us to cautiously propose a first series of implications regarding the roles that these players could play in each cycle. These roles suppose ways in which these actors could contribute to each cycle, given their current institutionalized forms. The roles are summarized in Table 9.

Table 9. Roles of firms, governments and universities in the three types of cycles

Players	Type of cycle: Science coevolution	Technology recombination	Experience continuity
Private firms (industry associations)			
- roles (games) with low demand specificity (anchors)	Science runner	Architecture navigator	Asset optimizer Experienced marketer Secure traveler Hasty newsmaker
- roles (games) with high demand specificity	Research toolmaker	System integrator	Tandem learner Niche advisor Program explorer
- funding roles		Leverage-venturer	Stingy-investor
Universities (scientific community)			
- knowledge roles	Knowledge provider	Knowledge incubator	Design rules developer
- other roles	Direction legitimator	Exploration enabler	Research contractor
Governments (nonprofits)			
- funding roles	Gatherer-benefactor		Lifecycle supporter
- other roles		Convener/coordinator	

Given the possibility of differentiated systems, connected by rather strong resource flows, which run across the customary boundaries between large sectors (two-digit), the main issue for firms is to understand and align with these flows. In the science-coevolution cycle, the anchor role for firms appears to be science-runners, actors who take ideas from science and productize them. The example of biotechnology shows that even a small fraction of successful firms stimulates the emergence of new startups and induces funds to support them. Research toolmakers are a derivative role, which can serve as a secondary avenue for firms that develop a technology platform but cannot transform it into a product in the period imposed by funding requirements. They depend for their survival on the existence of customers with high demand specificity and strong financial means. However, in our view, in the current institutional setting, with its pressure for fast return and investment focus, private firms can hardly play the funding role of "gatherer-benefactor". This role is probably best performed by a community of collaborative financial entities, more patient and sheltered from the periodic disenchantment waves that affect indiscriminately all initiatives, openly discussing and passing each other opportunities. Given the current institutional realities, a series of government agencies, supplemented by non profit entities, including the scientific community, looks best for this role. Private entities can participate in funding at later stages. Yet, "leverage venturers" may still be too impatient for the critical late stages of development, while large firms that play strategic investors, such as pharmaceutical giants, are too subjected to capability- and segment-centered strategic models to profit from all knowledge ramifications on which the science-coevolution cycle is built.

It is in the technology recombination cycle that private firms play most of the key roles. The anchor role is played by "architecture navigators," jockeying for positions among evolving modules and architectures for complex systems. "System integrators" play a derivative role; they feed on this continuous offering and reorganization by architecture navigators to package offers for customers with high demand specificity and strong finances. Unlike "research toolmakers", "systems integrators" target firms outside their resource renewal cycle, say in the experience continuity cycle, which is another way of absorbing funds into the cycle and passing them along to architecture navigators via module purchases. In addition, much shorter development cycles, based on reusing the latest technologies and products, some still in the design phase, matches the interests of less patient capital, and hence of firms that play the role "leverage venturers." These can be either venture capitalists or large firms, who redistribute innovation funds to new yet related technologies.

In the experience-continuity cycle, firms are also of utmost importance. In fact, resource flows could contained within one or a few firms, as they play the role of stingy-investor for their own innovation and serve as an anchor for other firms. Which game a firm would choose depends on its capabilities. For anchor roles with low demand specificity, the choice depends on whether activities depend on the complex large-scale operational assets (asset optimizers), or whether they produce quite complex artifacts (experience-marketers), on whether products can affect the safety and health of users (safe travelers), or none of the above (hasty newsmakers). For roles with high demand specificity, the choice depends on whether the offering is a more generic input (tandem learner), the answer to a very specific problem provided with standard technologies (niche advisor), or the answer to a very specific problem provided with advanced technologies (program explorer). The key issue for firms is what we can call the "structuring trap." Given the low knowledge dynamism, some firms could benefit from too strong structural protection, in which say economies of scale and learning could be supplemented by safety regulations, tariffs etc. This, in our view, is what made some sectors go to the very end of the innovation life cycle, basically stop innovating altogether. Sectors such as pulp and paper, electricity and to some extent aviation and automotive, have fallen into this trap. As will be discussed below, government intervention may be justified for such sectors.

With respect to the role of universities, and scientific communities, we argue without surprise that their role is crucial in the science-coevolution cycle. They perform the scientific research that is the basis for understanding complex natural processes, such as certain diseases, and they can also provides guidance that would help other entities orient their investment in promising directions. It is with respect to this cycle, we believe, that a focus on intellectual property protection and encouragement to patent, as well as university-industry interface institutions will have the most beneficial effect, given the need for high structuring potential and given the particular role of science runners, individuals who also carry tacit knowledge. With respect to the technology recombination cycle, universities can also originate some important knowledge and ideas, but their main role would be create an information exchange, where innovators, mostly undergraduate students, will learn about the latest technologies, develop skills and painlessly attempt new technological combinations. This is very different from the role played in the science-coevolution, where professors and graduate students produce scientific knowledge. Finally, for the experience-based cycles, universities could help formalize the design rules, for example engineering models and tables, as well as perform some punctual research tasks on a contract basis, a role similar to that played by niche advisors.

With respect to the role of government agencies and programs, we argue that its most productive role is to play a "gatherer-benefactor" role by supporting innovation, particularly science-runners, in the science-coevolution cycle. As discussed above, this is justified by the fact that "leverage venturers," concretely venture capitalists, next in line in terms of patience for return on investment, are probably not patient enough for the long cycle required to transform knowledge into products in the face of complex natural phenomena, and not ready to follow the continuous ramification of opportunities and technological knowledge that takes place in the face of such phenomena. Governments can play part of this role also indirectly, of course, by co-financing universities and other research institutions. A broad support for these institutions is particularly interesting if it amounts to supporting sectors that are above the diagonal in figure 2. On the other hand, governments need to be more selective when supporting sectors below the diagonal. Firms below the diagonal are already overprotected, so they often don't need and want to take the risks needed to innovate. In our view, this kind of support should target two groups. The first, is to help sectors that have fallen in the structuring trap but face unexpected competition, such as cheap products from developing countries, reposition themselves inside a healthy experience-based or other cycle. The second case is when these sectors are crucial for solving key societal challenges, such as global warming. These sectors could be helped to raise themselves from the structuring trap, and join or create a technology recombination and, especially, a science-coevolution cycle. Such attempts would be crucial for solving the energy and climate problems facing humanity. In addition to this "lifecycle supporter" role, governments, but also non profit entities, can also play the role of convener and even sometimes coordinator, for example by enforcing a standard, in the technology recombination cycle.

The theory presented in this paper could also contribute to other issues related to innovation. First, it could inform the understanding of sectors and refinement of industrial classifications. In our view, these classifications must also take into account the resource flows and the specific roles played by firms. This suggests two important levels or classification: sectors, as systems composed of firms collaborating symbiotically along the same resource reproduction cycle, and sub-sectors, as strategic groups composed of firms occupying the same value creation niche along a cycle. The theory can also shed light on the issue of radical innovation, which is often presented as required but very difficult for large established firms. However, we suggest that radical innovation is not only unnatural for firms engaged in the experience continuity and technology recombination feedback cycles, but perhaps is even counterproductive, because it will disrupt the niches on which they depend. Innovation is a systemic process based on flows of knowledge and funding. By disrupting them, the system may not move to a higher cycle but cease to innovate.

The paper has, of course, several limitations. The empirical part is based on psychometric measure of managerial perceptions. These perceptions can be influenced by beliefs that are taken for granted in a given sector. Therefore, it is important for further research to establish objective indicators for the variables we measure and to test our predictions based on econometric data. Moreover, it is important to use case studies of sectors in order to "measure" the resource flows more directly, rather than infer their existence from the propensities and relations of firms.

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Table 1. Comparisons among the three cycles

Cycle	**Science coevolution**	**Technology recombination**	**Experience continuity**
Dominant type of innovation	Radical - new principle, new architecture	Architectural - old principle, new architecture	Incremental - old principle, old architecture
Knowledge dynamism - forward flow - feedback flow	High - new explanations - research questions, data, ideas	Average - new technology combinations - new modules and products	Low - better design rules, new forms - new operational learning
Condition of persistence - knowledge complexity	High Complex natural phenomena	Average Complex technological systems	Low Complex artifacts
Roles along knowledge loop (italics denote anchor roles with low demand specificity)	*Science runner* Research toolmaker	*Architecture navigator* System integrator	*Asset optimizer* *Experienced marketer* *Secure traveler* *Hasty newsmaker* Tandem learner Niche advisor Program explorer
Financial dynamism - forward return expectation - feedback lateral deviation	High - distant, uncertain - new technology, new firm	Average - proximate, uncertain - related technology, new firm	Low - proximate, certain - related product, same firm
Conditions of persistence - structuring complexity	High - discrete (yes/no) effects (safety regulation, IP protection)	Average - highly non-linear effects (technical compatibility)	Low - mildly non-linear effects (scale, learning, reputation)
Roles along financial loop	Gatherer-benefactor Leverage-venturer Stingy-investor	Leverage-venturer Stingy-investor	Stingy-investor

APPENDIX A
Measuring conditions in innovation systems

Results reported in this paper are based on measuring the perceptions of a large sample of firms about knowledge dynamism, structuring potential, and demand specificity in their sector, as well as other aspects such as inflows of funds, network relations, and innovation performance. In this appendix, we discuss the psychometric scales used to capture these perceptions. If no explicit mention is made, measures use 7-point Likert scales, with 1 corresponding to “Totally disagree” and 7 to “Totally agree,” preceded by the title “The context of innovation in your sector” and the question “Please indicate how well the following statements describe your context.” The development of these measures is described in Miller and Floricel (2007a).

Measuring the knowledge production dynamism

Consistent with our assumption that firms are part of innovation systems with a certain degree of stability and cohesion, our measures of the perceived intensity of knowledge renewal suppose that firms are caught in a relatively stable knowledge production processes in the relevant system, and they take these processes as given. Our multidimensional measure captures, in light of the theoretical concepts, the production of scientific, technological and experiential knowledge. Moreover, each dimension has two items, to capture not only knowledge inflows but also feedbacks inside the sector or from sector to external partners, which contribute to maintain the renewal dynamics. Respectively, for scientific knowledge, one item captures inflows from the academic world, while the other, feedbacks from technological activities towards academia. For technological knowledge, for which processes are more endogenous, one item captures the flow of products and technologies, and the other, collaborative development, which includes feedback flows. For experiential knowledge, one item reflects reliance on a stable generic knowledge base, while the other, the gradual enrichment of this base, as the experience accumulated inside firms slowly becomes common knowledge and is translated into better generic models and databases.

Table A.1 Items used to measure the dynamics of knowledge production in innovation systems

Items	Average	Standard deviation	Rotated factor loadings		
			Science	Technology	Experience
Intensity of scientific knowledge production (Cronbach’s Alpha = 0.737)					
Knowledge production in the academic fields relevant for our sector is very intense	4.49	1.50	**0.892**	0.091	0.004
Our sector contributes a lot of data, ideas and papers to academic research	4.22	1.67	**0.863**	0.154	-0.106
Intensity of technological knowledge production (Cronbach’s Alpha = 0.544)					
New knowledge results mainly from intense interactions between firms	4.37	1.50	0.151	**0.801**	-0.004
New technologies build on the latest technologies of other firms in the sector	4.53	1.42	0.072	**0.832**	0.102
Intensity of experiential knowledge production (Cronbach’s Alpha = 0.336)					
All firms in our sector rely on the same stable technological base	4.40	1.58	-0.171	0.118	**0.714**
New knowledge results from the gradual accumulation of experience inside firms	5.26	1.25	0.076	-0.023	**0.818**

Table A.1 presents the items that measured firm perceptions on these dimensions, and descriptive statistics and factor loadings resulting from analyzing these items with the Principal Components and Varimax rotation procedure in SPSS 13.0. The simple structure resulting from the factorial analysis and the fact that the pairs of items for the direct and the feedback flow load strongly on the same factor supports our theoretical assumptions on the emergence of feedback flows when feed forward flows are strong.

Measuring structuring influences

The structuring influences include three groups of factors. The first type includes protective barriers created by macro-level institutions, such as health and safety regulation and intellectual property protection. Products in many sectors have no value if deemed illegitimate within these institutional arrangements. The second type includes technical compatibility factors, which have been shown to trigger strong nonlinear structuring processes in the sectors they affect. Because products have much lower value if they cannot interoperate and interconnect with other products, technical systems and infrastructures, buyers have strong preferences for one offering over others. The third type includes economic structuring logics. For example, by increasing operation scale, eliminating inefficiencies through learning some firms improve the cost and quality of products, increasing the customer preference for them. The items used to measure these three factors are listed in Table A.2 along with descriptive and reliability statistics as well as factor loadings.

Table A.2 Items used to measure the structuring factors that create niches in innovation systems

Items	Average	Standard deviation	Rotated factor loadings		
			Institutional	Technical	Economic
Macro-level conditioning (Cronbach's Alpha = 0.645)					
Regulatory approval is a critical prerequisite for commercializing any new product	4.47	2.05	**0.824**	0.066	0.016
Time and resources needed to obtain regulatory approval deter *me too* innovations	3.76	1.77	**0.874**	0.032	0.082
Intellectual property protection enables firms to capture all the value from innovations	4.33	2.06	**0.557**	0.103	0.133
Technical structuring logics (Cronbach's Alpha = 0.768)					
Products must interconnect with other products or systems to have value for customers	5.52	1.54	0.079	**0.901**	-0.035
The operation of our products relies on the operation of many other technical systems	5.00	1.62	0.112	**0.884**	0.117
Economic structuring logics (Cronbach's Alpha = 0.512)					
Large unit cost reductions can be obtained by increasing the scale of operations	4.93	1,59	0.144	0.071	**0.655**
Improving production processes brings much higher returns than product innovation	4.29	1.51	0.033	0.006	**0.736**
Most of the products of our sector face severe cost constraints	4.96	1.52	0.053	0.008	**0.723**

Measuring demand specificity

The innovation literature suggests that the nature of customers and customer relations is a key influence on innovation. It points out to differences between specialized industrial markets, which call for relational innovation, and mass markets, which call for arm's length transactions; between lead users, pushed to become innovators by unfulfilled demands (von Hippel 1998), and regular customers, content with what markets have to offer; and between current advanced customers, who demand more of the same kind of performance, and marginal customers, which can only be served with disruptive innovation (Chirstensen 1997). These considerations regarding the role of customers, the extent to which they provide advanced knowledge and inciting specialized innovation form the demand specificity dimension. Table A.3 shows the items used to measure the customer role.

Table A.3 Items used to measure the role of customers

Items (**Cronbach's Alpha = 0.535)**	Average	Standard deviation
Customers provide significant expertise about how our products operate	4.98	1.51
The customers served by firms in our sector have very complex needs	5.39	1.45

Measuring relations to governments, venture capital and other firms

In addition, we measured certain resource flows, via the extent to which prevailing institutions provide or enable ex-ante inflows of resources to support innovation activities in the meso-level system. The two items used to measure this conditioning influence are presented in table A.4.

Table A.4 Items used to measure the extent to which macro-level institutions enable ex-ante inflows of funds into the meso-level system

Items (**Cronbach's Alpha = 0.598)**	Average	Standard deviation
Governments allocate a lot of resources to support research and innovation	3.41	1.66
Innovative startups have easy access to funding (seed money, venture capital, IPOs)	3.20	1.49

Regarding the non-financial roles played by governments, universities and other firms, which would induce the focal firm to form relations with other organizations, we measured the relevance of the role using a 7-point importance scale (see Table A5). Then respondents rated dichotomously (effectively yes/no) by checking in the appropriate box whether the role was performed, respectively, by other firms, government, or universities.

Table A.5 Items used to measure network partners' fulfillment of enabling roles

Innovation enabling role	**Importance of role** Not at all important … Somewhat important … Extremely important	**Types of organizations that are important in performing this role (Please check all that apply, only if role is important.)**		
		Other firm	Government department or agency	University
Helps our firm learn about new technologies	1 2 3 4 5 6 7			
Helps our firm learn about new markets	1 2 3 4 5 6 7			
Provides our firm with business advice	1 2 3 4 5 6 7			
Identifies knowledgeable individuals	1 2 3 4 5 6 7			
Identifies partner firms and organizations	1 2 3 4 5 6 7			
Facilitates innovation involving multiple organizations	1 2 3 4 5 6 7			
Promotes enabling standards	1 2 3 4 5 6 7			
Undertakes innovative activities on our behalf	1 2 3 4 5 6 7			
Forces us to innovate by changing regulations	1 2 3 4 5 6 7			
Forces us to innovate through social pressure	1 2 3 4 5 6 7			

Measuring the emphasis in value creation

To support analyses referring to value creation, we measured respondent perceptions regarding the capabilities that need to be emphasized in order to innovate (see table A.6). Items in table A.6 were measured using 7-point importance scales, preceded by the question "Which of following capabilities are important for producing customer value in your sector?"

Table A.6 Items and factors measuring the importance of value creation capabilities

Items	Avg	Std dev	Rotated factor loadings (variance explained)			
			Matching (20.1%)	Aligning (15.8%)	Engineering (14.5%)	Productizing (13.0%)
Productizing (Cronbach's Alpha = 0.468)						
Capability to transform the results of academic research into useful products	4.46	1.67	0.222	-0.029	-0.017	**0.803**
Capability to legitimate products by obtaining regulatory approvals	4.28	1.83	-0.132	0.275	0.326	**0.682**
Aligning (Cronbach's Alpha = 0.700)						
Capability to gain acceptance for products as facto standards	4.65	1.50	0.171	**0.605**	0.049	<u>0.489</u>
Capability to spur creation of complementary products around open architectures	4.29	1.56	0.305	**0.729**	-0.069	0.188
Capability to align with dominant solutions in order to avoid disruption for clients	4.81	1.48	0.149	**0.808**	0.248	-0.063
Engineering (Cronbach's Alpha = 0.635)						
Capability to engineer products with absolute reliability, safety, and security	5.72	1.48	0.138	0.253	**0.672**	0.296
Capability to continually reduce costs (including through supply chain design)	5.52	1.40	0.158	-0.003	**0.804**	-0.040
Capability to continually improve the quality of products	5.86	1.04	<u>0.529</u>	0.009	**0.531**	0.173
Matching (Cronbach's Alpha = 0.743)						
Capability to anticipate and solve customers' problems in special applications	5.78	1.21	**0.546**	0.201	0.314	-0.033
Capability to increase product variety while keeping customization costs low	4.98	1.49	**0.710**	0.173	0.169	0.040
Capability to continually introduce novelties (new products, releases, and functionalities)	5.02	1.54	**0.815**	0.083	-0.069	0.226
Capability to design solutions that enhance the full cycle of customer experience	5.22	1.41	**0.642**	0.357	0.228	-0.016

Based on Miller and Floricel (2004, 2007) we grouped these items into 4 value creation dimensions, called respectively productizing, aligning, engineering and matching. Productizing refers to the capability to create new customer value by taking scientific discoveries and using them to develop new technologies and, eventually, transform these into legitimate products. Aligning refers to value created by reducing customer uncertainty regarding the interoperability of products and to the capability to design innovative products that will impose a standard for interoperability or will be compatible with an existing standard. Engineering refers to value creation approaches that reduce customer cost by using generic engineering knowledge and accumulated experience to increase the scale, efficiency and reliability of production and operation systems as well as to improve the quality of products. Finally, matching (Pavitt 1988) refers to the ability to understand in detail user needs, problems and experience cycles, and to produce innovations that create value by answering more closely to these issues and by inducing a perception of novelty. Results of the factor analysis (principal component procedure with Varimax rotation in SPSS 13.0) that tested whether the intended items group to form these dimensions are presented in last four columns of Table A.6. Indeed, the resulting structure is quite simple and the few exceptions make sense. For example, the fact that the third item loads both on the second and the fourth factor may be due to the ambiguity of the word "standard" it contains, which can be understood both as a "dominant design" (Abernathy and Utterback 1978) and as a "normative architecture or interface" ensuring coordination between interoperating subsystems (see for example Shapiro and Varian 1999). The fact that the eighth item loads both on the first and the third factor may be due to the ambiguity of the word "quality" which traditionally meant "absence of defects" but, more recently, also acquired the meaning "responding closely to user needs" (Hauser and Clausing 1989). This suggests that factor scores can be safely used in further analyses. It is also interesting to note that productizing, aligning, and engineering, which we expect, respectively, to dominate the science coevolution, technology recombination and experience continuity cycles, explain between 13% and 16% of the total variance, while matching, which we expect to distinguish between games inside cycles, explains more than 20% of the variance.

APPENDIX B
Industry Sectors

NAICS	Knowledge	Structure	Customer	Label
23	-0.65	1.47	-0.09	Construction
212	-0.87	0.78	-0.07	Mining and Quarrying (except Oil and Gas)
311	-1.71	0.69	-0.55	Food Manufacturing
333	-0.31	0.43	-0.29	Machinery Manufacturing
517	0.28	1.50	-0.27	Telecommunications
2211	-0.53	-0.20	-0.43	Electric Power Generation, Transmission and Distribution
3221	-1.83	-1.78	-0.70	Pulp, Paper and Paperboard Mills
3222	-2.01	0.10	-0.74	Converted Paper Product Manufacturing
3251	-1.16	-0.13	-0.15	Basic Chemical Manufacturing
3254	1.67	1.09	0.22	Pharmaceutical and Medicine Manufacturing
3256	-1.29	-2.67	0.12	Soap, Cleaning Compound and Toilet Preparation Manufacturing
3259	-0.84	-1.88	-0.21	Other Chemical Product Manufacturing
3311	0.59	0.22	0.31	Iron and Steel Mills and Ferro-Alloy Manufacturing
3313	-0.66	-0.68	0.07	Alumina and Aluminum Production and Processing
3321	-2.22	-0.90	-0.07	Forging and Stamping
3328	-0.46	0.58	-0.54	Coating, Engraving, Heat Treating and Allied Activities
3331	-0.92	0.81	0.25	Agricultural, Construction and Mining Machinery Manufacturing
3332	-1.91	-1.56	0.44	Industrial Machinery Manufacturing
3335	0.49	0.50	0.83	Metalworking Machinery Manufacturing
3341	1.63	-0.70	0.66	Computer and Peripheral Equipment Manufacturing
3342	0.32	-0.29	0.08	Communications Equipment Manufacturing
3343	0.24	1.47	0.18	Audio and Video Equipment Manufacturing
3344	0.60	-0.54	-0.20	Semiconductor and Other Electronic Component Manufacturing
3345	-0.32	-0.80	-0.01	Navigational, Measuring, Medical and Control Instruments Manufacturing
3353	1.40	1.34	0.05	Electrical Equipment Manufacturing

3361	0.96	1.21	0.02	Motor Vehicle Manufacturing
3363	-0.55	0.80	0.31	Motor Vehicle Parts Manufacturing
3364	0.89	1.92	0.56	Aerospace Product and Parts Manufacturing
3366	-0.73	-0.98	0.58	Ship and Boat Building
3391	0.42	-1.06	-0.05	Medical Equipment and Supplies Manufacturing
5112	1.04	-0.18	1.04	Software Publishers
5413	-0.04	0.49	-0.18	Architectural, Engineering and Related Services
5415	0.11	-0.20	0.11	Computer Systems Design and Related Services
5417	2.05	-0.84	0.31	Scientific Research and Development Services