An investigation of the innovation performance in the capital goods sector in Colombia: using the System Dynamics approach

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Abstract

The innovation performance of a firm is addressed using the System Dynamics method. The problem that motivated this study is the lack of a comprehensive theory that explains both the poor innovation performance of the Colombian industry and its scarce level of the technological capabilities. Although there are a number of attempts to explain the problem, their causal structures are not fully specified and their results have not been evaluated with regard to whether they altogether constitute a coherent and consistent theory of the underlying causes explaining the observed dynamics. Robledo's (1997) research on the innovation process of the Colombian capital goods industry is examined in detail. We tested that the dynamics that Robledo describes can be produced by the causal factors he postulates. In Colombia, industrialists, academics and policy-makers need to do both acknowledge innovation as a learning process and estimate the intangible benefits of R&D.

Key words—capabilities, capital goods, innovation, and system dynamics.

1. Introduction

In the definition of our research theme, we summarize two issues which have been identified in the Colombian context:

- The evident disadvantage with regard to science and technology (S&T) of the Colombian industry compared to other countries, coupled with the scarce level of technological capabilities necessary to carry out innovation activities (Durán, Salazar and Ibáñez 2000; Hansen et al 2002; Maloney 2002; de Ferranti et al 2003;UNESCO 2004; RICYT 2005).

- The lack of research which analyzes the above problem from a structural (causal) point of view (Mytelka 1978; Alcorta and Peres 1998; Cassiolato, Villaschi and Ramos 2003; Vargas, Malaver and Zerda 2003; Villaschi and dos Santos 2003).

In this paper we address the innovation performance of a firm within the capital goods sector in Colombia using the System Dynamics method. The problem that motivated this study can be stated as the lack of a comprehensive theory that explains both the poor innovation performance of the Colombian industry and its scarce level of the technological capabilities necessary to carry out innovation activities. Although there are a number of attempts to explain the problem, their causal structures are not fully specified and the results of these have not been evaluated with regard to whether they altogether constitute a coherent and consistent theory of the underlying causes explaining the observed dynamics (behavior).

To extend the discussion in the literature about the innovation process in Colombia, we examine an existing theory in detail, formalizing it to investigate how well the theory accounts for the phenomena its author set out to explain. Our focus is Robledo's research on the innovation process of the Colombian capital goods industry, in which Government Institutions (GIs) and Higher Education Institutions (HEIs) play a key role.

Qualitative models might properly represent complex feedback structures; nevertheless, they omit parameters, functional forms, external inputs, and initial conditions needed to fully specify the structure of a system, understand their dynamics, and test the model itself.

Because nonlinearity, delays and feedback are central to the innovation process (Kay 1998; Griliches and Klette 1990; Milling 2002; OECD 2005), a causal modeling approach suitable for capturing dynamics is needed. System dynamics offers the ability to bring a model to life, to see the consequences of structural assumptions, to try out "what-ifs", and to challenge managerial intuition (Vennix and Gubbels 1994, 139). As Sterman (2000) asserts, formalizing qualitative models and testing them via simulation often leads to radical changes in the way we understand reality. Likewise, Forrester states that verbal statements need to be clarified by translating them into less ambiguous forms and into a form that will allow us to experiment with the implications of the statements already made (Forrester 1961, 44).

It follows that Robledo's verbal descriptions of causal relationships are formalized in the form of a System Dynamics model. It is expected that this approach will improve our understanding of the accumulation of the capabilities affecting the innovation performance observed at micro and macro level; and, as a result, it will improve decision making and future policy design.

In responding to the challenges posed by the Millennium Development Goals, and the fact that science, technology and innovation underpin every one of these goals, we expect to make a significant contribution to the UN (2005) recommendations about the role played by HEIs and GIs in innovation and the role of the industrial firm as a locus of learning.

It is worth mentioning that this research does not deal with the innovation performance of a specific firm, partly because the product development process is usually firm specific, therefore better dealt with at the appropriate level, and because Robledo draws its conclusions from the empirical research he conducted[1]. This research emphasizes that the role that industrial firms can play in innovation and social well-being depends largely on both the internal skills they have at their disposal and the firm's interaction with HEIs and GIs.

In addition, the data given by Robledo is not a sufficiently complete basis for translating his research findings into a system dynamics model. Thus, we draw on theory and have searched for other types of data to fill in the gaps between the statements he makes and the structural relationships.

2. Describing the innovation process

2.1. Main results of Robledo's research

First of all, we present briefly the concept of paradigm adopted by Robledo. In his study, Robledo supports the hypothesis that technological innovation and institutional change are interdependent; and he asserts that a paradigm is a particular kind of institution which, as said by Johnson (1992, 26), is a set of habits, routines, rules, norms and laws, regulating the relations between people, and shaping human interaction. Moreover, paradigms act pervasively at the level of the awareness and decision making functions in organizations, strongly affecting the development of the innovation process in firms and the accumulation of innovation capabilities in the whole industrial innovation system (Robledo 1997, 236).

There are visible expressions of the cumulative effect of the dominant innovation paradigm present in the Colombian capital goods innovation system; as is described by Robledo:

> "The Colombian capital goods innovation system:
> 1. Has disregarded innovation as a valid development alternative;
> 2. Has internalized conceptions which are akin to traditional economics, characterized by identifying 'knowledge' with 'information', by reducing the benefits of R&D to their direct results, and by assuming that innovations can easily be adopted, provided that the respective 'best practices' are introduced;
> 3. Has failed to accumulate research capabilities for innovation, by focusing almost exclusively on accumulating imitation capabilities for production;
> 4. Has created barriers to collaboration which hinder the establishment of innovation networks among users, producers, and research organizations."

The manifestation of the paradigm through such particular elements has created an intricate problem; the little generation and accumulation of innovation capabilities within the system's organizations impedes a shift in the dominant paradigm, thus the inability to develop skills is reinforced all over again.

Besides the identification of effect that the paradigm exerts on the innovation system, Robledo investigated the facts determining the paradigm formation as well as the role that HEIs and government institutions might play in the process of paradigm shift. Notwithstanding the importance of these latter issues in explaining Robledo's research purpose and in the conclusions he attained, we will emphasize on the effect that the paradigm exerts on the development of the innovation process and the development of innovative capabilities within firms. As the Oslo Manual (OECD, 1992) and the

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[1] Robledo conducted an empirical research based on data from a representative sample of firms in the Colombian capital goods industry.

Millennium Project (UN, 2005) explain, and to be consistent with Dosi, Freeman and Fabiani (1994) and Nelson and Winter (1982) cited by Alcorta and Peres (1998) we consider important to focus our analysis on the firm because:

> "Within organizations, however, firms play a central role in the NSI [National System of Innovation]. It is they which are responsible for innovating. They must develop the competencies in product design and production, in overall management and assessment of consumer needs and in linking to upstream and downstream suppliers and distributors. It is they that must search, develop R&D 'routines' and further engage in the learning processes for innovation."

As far as the role of HEIs and government institutions is concerned, our analysis addresses the influence exerted by the interaction between the firm and these agents on the rate and direction of development of innovative capabilities within the whole innovation system.

2.2. Translation into the SD approach

We present Robledo's findings by putting them into categories relevant for the formal modeling. This procedure is based on the method followed by Sastry (1997).

We identified statements describing constructs (variables), collecting into categories those that appeared to refer to the same construct, and analyzed statements describing relationships between constructs.

TABLE I
DESCRIPTION OF THE GIS' POLICY-MAKING CAPABILITY

Category	Example
Construct	GIs' Policy-Making Capability
Definition	"Government institutions should accumulate capabilities for efficient policy making"
Structure / Relationship	"efficient and effective policies are likely to emerge only from a very well informed policy-making process, which in turn requires continuous support from the HEIs in the form of provision of advanced knowledge and skills"…""firms have also failed to recognize the relevance of innovation, which has preventing them from interacting with the government in such a way that policies are questioned and a learning process takes place within the government itself"
Dynamic Behavior	"lacking adequate policy-making capabilities, the Colombian government has never considered the accumulation of innovation capabilities a requirement of industrialization which deserves to be addressed by public policies"

Table 1 and table 2 present two variables out of the set variables identified as the guide posts for constructing the causal framework of the model. The construct refers to the identified variable, necessary to be tracked. The definition is an explanation of the construct as it is set out by Robledo. In the structure / relationship, a description of how one variable influence another is given. Dynamic behavior sets the pattern of evolution of the variables over time. It is worth mentioning that there are neither clear relationships nor patterns for all the variables that we included in the model.

TABLE II
DESCRIPTION OF THE FIRM'S INNOVATION CAPABILITY

Category	Example
Construct	Firm's innovation capability
Definition	"needed to develop more advanced and complex product and processes"..."if some kind of technological capability is needed, it is the sort of capability required to adapt and improve the use of the technology employed in the productive process"
Structure / Relationship	“supposedly automatic and costless by-product of the first [production capacity]…Colombian industrial firms did not accumulate innovation capabilities… principally because innovation itself was not perceived as a valid pathway towards industrial development"
Dynamic Behavior	"where firms lack such capabilities…it is impossible for them, or otherwise fruitless, to establish collaborative relationships with academic institutions and other firms"…"academic-industrial linkages are weak and fail to produce successful interactions which otherwise would lead to a cumulative development of the learning process"

3. Formalizing the innovation process

3.1. The dynamic hypothesis

In dealing with the low level of innovation capabilities accumulated by the Colombian industrial innovation system and hence its poor innovation performance, Robledo (1997, 222) argues:

> “…the Colombian capital goods innovation system is caught in a complex sequence of vicious circles which inhibits the development and accumulation of innovation capabilities, whose path-defining mechanism is a dominant innovation paradigm which acts forcefully at the level of the awareness and decision making processes, preventing organizations from accumulating innovation-related capabilities.”

The formulation of this hypothesis is our second step to asses whether the dynamics that Robledo describes can be produced by the causal factors he postulates as the origin of the problem. The dynamic hypothesis depicted as causal loop diagram is shown in Fig. 1.

We assume a firm invests in production capacity for two reasons; 1. to expand its current capacity; and 2. to replace the capital scrapped. Regardless of the reason, when the firm acquires new capital, the technology embedded in that capital has a higher technology level compared to the one existing in the current stock. As indicated by Robledo, firms within the Colombian capital goods industry see innovation as a by-product and cost-less benefit of their investments in production capacity.

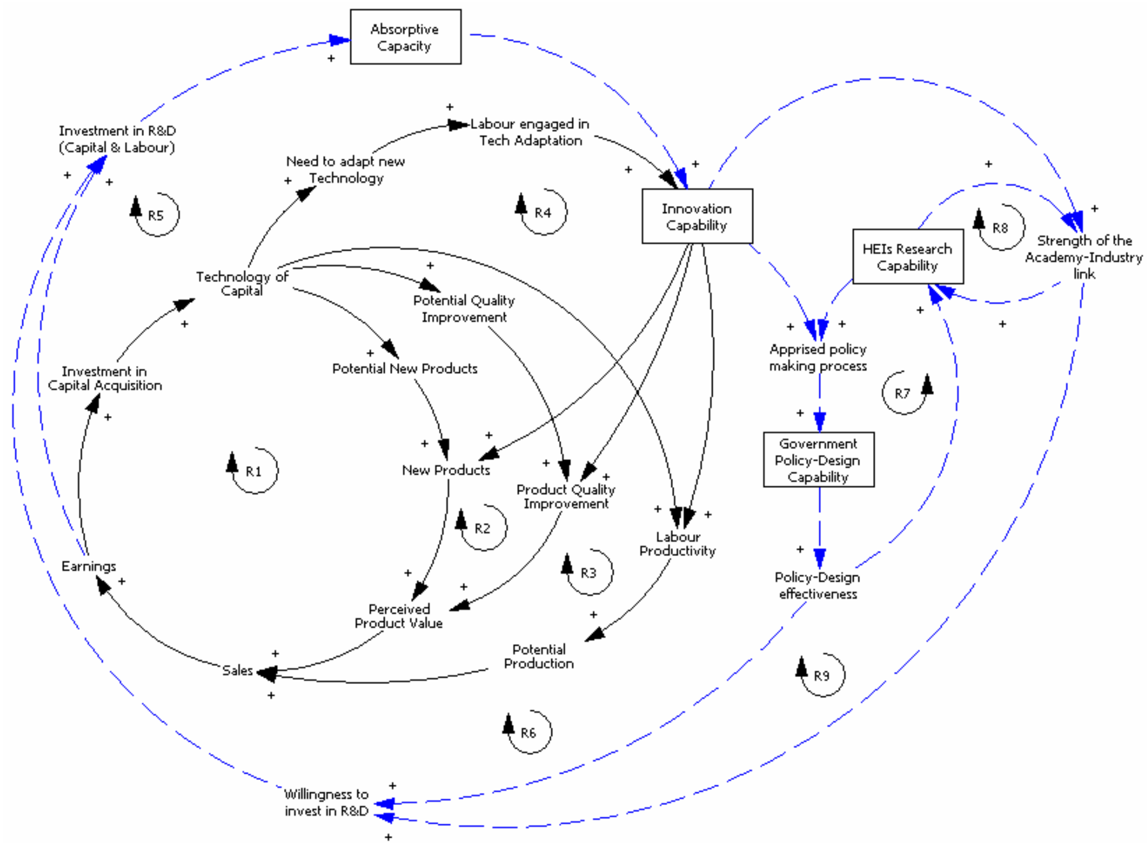

Fig. 1
The dynamic hypothesis

Beginning with loops R1 and R2, new capital with a higher technology level, once it has been adapted to the product development process, gives the firm the possibility to develop new products or to improve the quality of its current products. Thus as more new products or quality improved products are launched into the market, the product value perceived by the customer increases. The higher the perceived product value, the greater are sales and, as a result, the more the earnings will be. The higher the earnings, the more future investments can be made. Thus closing the new product development loop R1 and the product quality improvement loop R2. Besides the effect of the technology level on the product development and quality, the technology embedded in the capital also affects the labor productivity. The higher the labor productivity, the greater is the production capacity of the firm and, as a result, the higher the sales may be. The higher the sales, the more earnings and more investments will be made in production capacity, thus closing the loop R3.

As mentioned before, firms within the Colombian capital good industry believe they can use technology as a mean to innovate. Robledo reports that firms allocate personnel from production oriented functions to the product development process in order to improve the firm's innovation capability, i.e. 1. to build the capability necessary to adapt technology to the production process; and 2. to gain the knowledge required to materialize the potential new products and quality improvements that, in the end, will increase the firm's earnings and hence the investments in production capacity (loop R4). Robledo claims that the innovation capability gained by moving personnel from production to the technology adaptation task is not sufficient to realize 1 and 2 above. Moreover, production tends to concentrate the attention of the team members to the detriment of product development. Also, the innovation process demands specific skills that are different from those required for production. It follows that direct investments in research and development (R&D) are needed in order to recognize the value of new, external information, assimilate it, and apply it to commercial ends. The greater the resources allocated to R&D, the greater is the knowledge absorption capacity of the firm and the higher its innovation capability. This enables the firm to translate potential innovation into real outcomes, thus closing the loop R5.

Higher Education Institutions (HEIs) and Government Institutions (GIs) significantly influence the firm's willingness to invest in R&D, according to the study done by Robledo. If the firm recognizes the relevance of innovation and invests in R&D in order to accumulate innovative capabilities, then it will be able to interact with the government in such a way that public policies regarding science and technology are questioned, and as a result, the government has the opportunity to improve upon his policy-design task; in other words, a learning process will take place within the government itself. The higher the innovation capability of the firm is, the stronger are the industry-government linkages. This may lead the government to improve its ability to design policies that encourage science and technology activities, thus increasing the firm's willingness to invest in R&D (loop R6). Likewise, the more effective the policy-design process is, the more the research (and training) capabilities accumulate in HEIs. This, in turn, support the policy design process by providing advanced knowledge and skills to the GIs, thus increasing the government policy design capability (loop R7).

Assuming that research and advanced training capabilities are accumulated sufficiently in HEIs, the academic-industrial linkages will be strong and they will succeed in their interactions, leading to a more intensive development of research capabilities at HEIs (R8). Assuming that innovative capabilities are accumulated sufficiently within industrial firms, and that the academy-industry linkages will be strong so that they succeed in their interactions, then this will encourage the firm to carry out direct investments in R&D (R9).

The dynamic hypothesis help us to understand that if firms fail to recognize the importance of investments in R&D and actually commit to such investments, they fail as well to develop the knowledge and skills needed in order to: 1. innovate; 2. support the government in its science and technology policy design process; and 3. interact with the academia in such a way that the firm will at the same time benefit from the knowledge developed at HEIs, and foster the learning process taking place at HEIs. Moreover, the capabilities accumulated within the HEIs and GIs affect the firm willingness to invest in R&D next time around. This circular set of causalities have been characterized by Robledo as a Gordian knot involving several reinforcing loops (denoted by the dash lines) that might lead to a pattern of behaviour in the form of virtuous or vicious cycle.

3.2. The reference mode

In order to contribute to the understanding of the poor innovation performance of the Colombian industry, our main objective is to asses whether the dynamics that Robledo describes can be produced by the causalities, i.e. causal relationships, which he postulates. Thus, as a reference mode we quote the following assertion:

> "We suggest that the dynamics of the learning processes in industrial innovation systems may give rise to a virtuous circle of accumulation of capabilities if the right conditions are given. Conversely, if these conditions are not fulfilled, it is more likely that the industrial innovation system is caught in a vicious circle where the accumulation of capabilities stops at a certain level (Robledo 1997, 82)."

Even though Robledo does not give a graphical representation of this reference mode, the phrase "virtuous circle" clearly suggests an exponential growth of capabilities. The phrase "vicious circle where the accumulation of capabilities stops at a certain level" suggests, as stated by Robledo, either a goal seeking or an S-shaped behavior.

3.3. The model

We formalize the conceptual model described above by presenting the causalities that constitute the model structure as postulated by Robledo, along with the literature used to complement the formalization when this is required.

The core of the model is the interplay between the firm's technological infrastructure and the product innovation and development process; these subsystems are highly dependant on the investment decision regarding research and development (R&D) made by firms. In this model the technological infrastructure and the product innovation and development process have been are integrated with generic system dynamics modules representing production and market.

Selected model sectors are reproduced here; the complete model is available from the author.

- The firm's technological infrastructure

Innovation involves processes of learning either through experimentation (trial and error) or through improved understanding (theory). Some, but not all, of this learning is firm specific (Pavitt 2003, 9). Such learning processes form the cumulatively augmented abilities and skills developed within the firm or, to be consistent with the literature on innovation, such learning processes form the innovative technological capabilities of the firm. These capabilities cannot be bought and sold; it does not imply that such skills are entirely immobile, they just cannot be entirely diffused either in the form of public or proprietary information (Dosi 1988, 1131).

In the model, we define a technological infrastructure that comprises both the in-house innovation capability and the marketing capability; these capabilities evolve (respectively) as a result of the firm's investments in: 1. research and development, and 2. customer relationships. These capabilities determine the firm's product development, manufacturing process and products' quality improvement.

In the formulation of the innovation capability we apply the concept of absorptive capacity postulated by Cohen and Levinthal (Cohen and Levinthal 1989; 1990) and frequently cited in the technological change literature. As indicated by Cohen and Levinthal (1990, 135), the absorptive capacity is firm-specific and therefore cannot be brought and quickly integrated into the firm. It is the firm's ability to identify, assimilate, and exploit knowledge from the environment, and represents a sort of learning that differs from learning by doing (1989, 570).

The formulation of the firm's stock of technical and scientific knowledge, given by Cohen and Levinthal, is insightful since it establishes that the firm can neither assimilate what is not spilled out by other firms and research organizations nor can it passively assimilate externally available knowledge. The firm must invest in its own research and development (R&D) in order to absorb any of the R&D output of its competitors and the knowledge generated in the government institutions and universities. However, the formulation does not reflect that the knowledge absorbed by the firm from the environment cannot increase indefinitely nor it considers the depletion of the stock. In addition, the formulation does not reflect the learning attribute of the absorptive capacity, which causes the absorptive capacity to accumulate.

In reality, the knowledge gain is constrained by the gap between the firm's own stock of knowledge and the extramural knowledge. The stock of knowledge can decrease by knowledge loss. And, the accumulation of absorptive capacity facilitates subsequent development of absorptive capacity. We address these drawbacks in the formulation of the firm's stock of technical and scientific knowledge that we use in this paper.

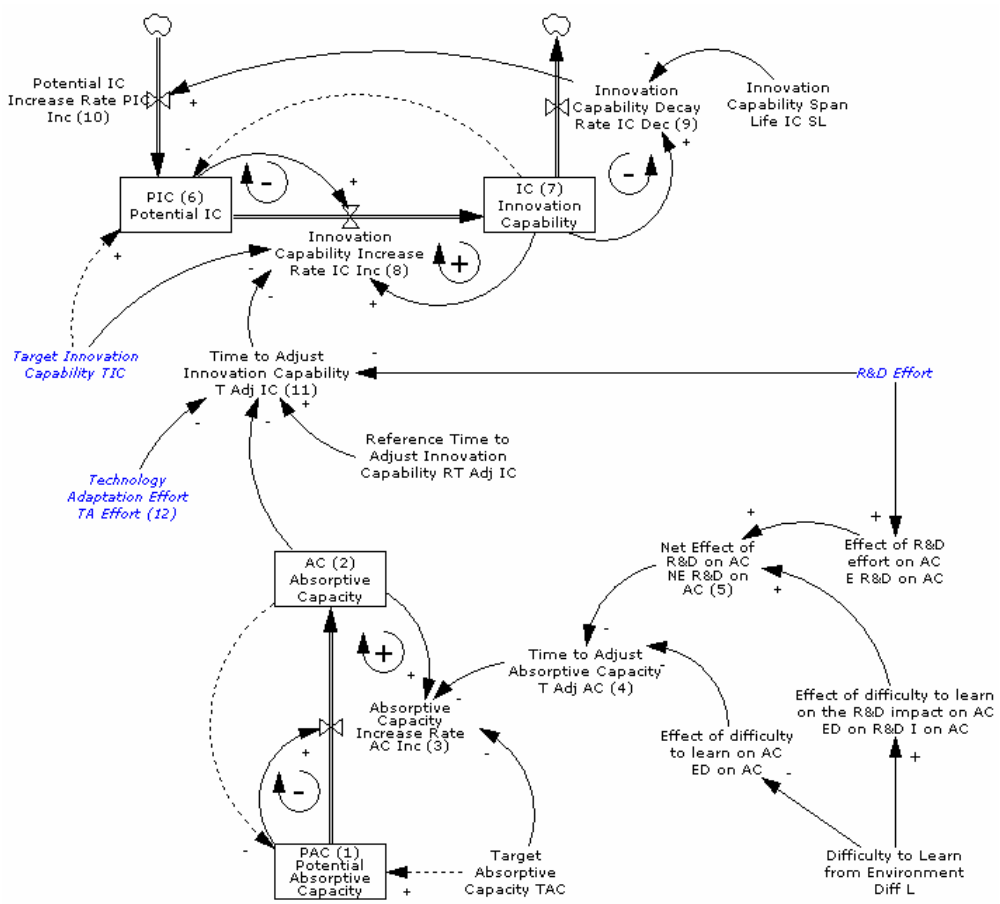

Fig. 2
The innovation capability

The formulation of the innovation capability depicted as a stock and flow diagram is shown in Fig. 2. The variables shown in italics are determined in other sector of the model. Capabilities are stocks; they can either be accumulated or depleted over time. The innovation capability represents the stock of knowledge defined by Cohen and Levinthal (1989) and comprises the technological capacity necessary in the capital goods industry.

There are three mechanisms used to accelerate the development of the innovation capability: The absorptive capacity, the R&D effort and the technology adaptation effort. In order to account for the learning and loss processes, both the inflow and the outflow of the capability depend on the current level of the capability itself. This formulation is consistent with the formulation of capabilities proposed by Warren (1992, chapter 9).

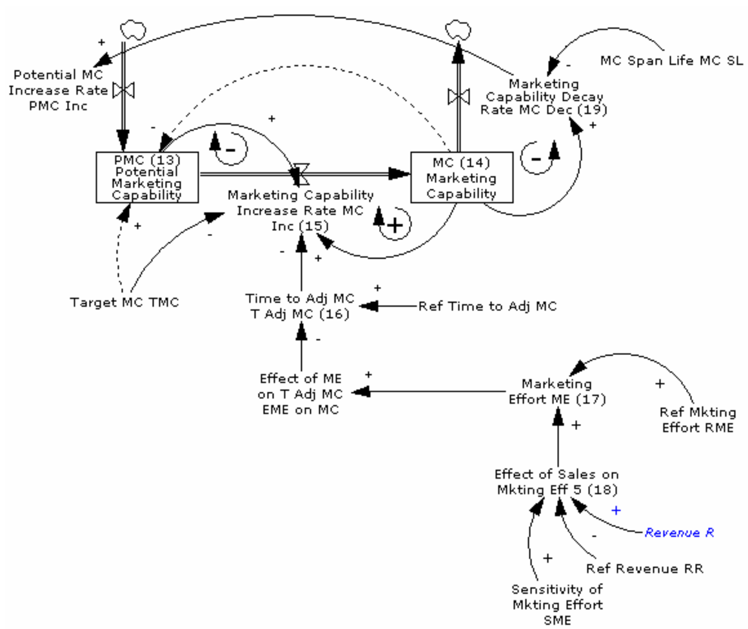

Fig. 3
The marketing capability

The formulation of the marketing capability depicted as a stock and flow diagram is shown in Fig. 3. The firm's marketing capability is a function of the capability itself, a target marketing capability and the firm's own marketing research endeavor which is assessed by the ratio between the marketing research expenditure and the revenue. The marketing research expenditure is one of the items in a firm's marketing budget and its aim is to yield information that allows the firm to identify and define market driven opportunities and problems. The marketing expenditure comprises the advertising expenditure, the marketing expenditure and the investments made to create customer relationships, as it is suggested by Dutta, Narasimhan and Rajiv (1999).

- The innovation and development process

We want to call attention to three assumptions we made regarding the concept of technological innovation: 1. process innovation is excluded; 2. product innovation refers to the development of new products to the firm, which might not be new to the market; and 3. product innovation is possible thanks to the development of the firm's capabilities. In addition, the matching process between the supply and demand of innovations is indirectly addressed by means of the marketing capability which allows the firm to screen customer needs and translate them into the product innovation and development process.

The capital goods sector is characterized by a wide range of products of varying degrees of technological complexity (in terms of design intensity). Although the innovation process is firm specific, we may draw a general picture of this process. We adopt the conceptual innovation and development process described by Gaynor (1996).

This conception of the innovation process is reported on both Robledo's analysis of the innovation underperformance of the Colombian capital goods industry and on the study cases undertook by Vargas, Malaver and Zerda (2003) regarding the Colombian metal-mechanical industry which is a sub-sector of the capital goods industry. In addition, these researches regard innovation as learning processes that involve several agents whose decisions interplay to affect the industry performance.

Since we aim to analyzing the interplay between the technological infrastructure described earlier and the product innovation and development process, the conceptual process postulated by Gaynor (1996) is reduced to the formalized structure of stocks and flows shown in Fig. 4 along with the variable name abbreviations and their equation numbers. New potential products accumulate in a stock of potential product innovations. As the feasibility of potential innovations is being evaluated, the product's design development starts. After designs have been completed and reviewed, prototyping starts. Once prototypes have been successfully tested, products flow to the designs ready for production. Products accumulate in this stock until products are launched into de market place. After the market release, the stock of designs in production increases. Finally when the products reach the end of their life cycle, they are scrapped, thus decreasing the stock of designs in production.

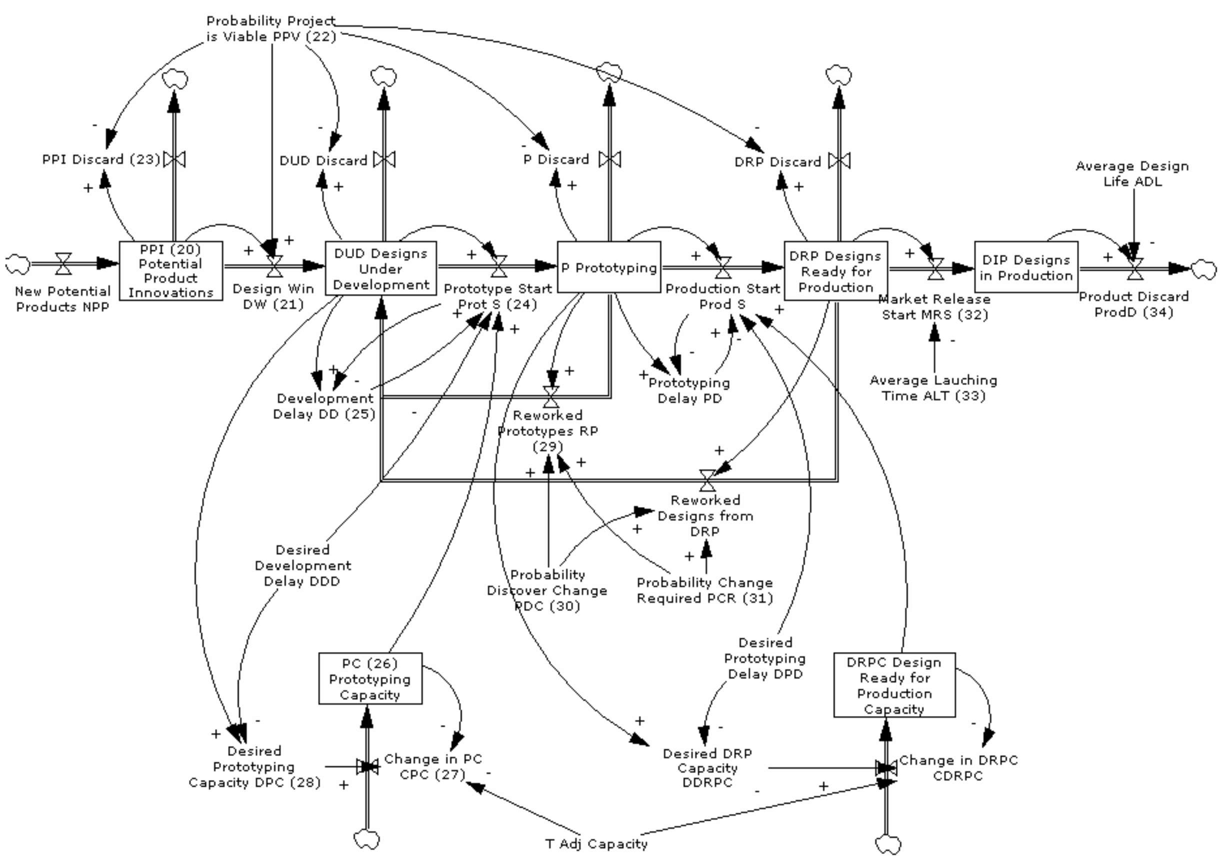

Fig. 4
Product innovation and development process

4. Results and discussion

4.1. Model validation

A model is a simplification of the real system; thus, the model validity is the usefulness with respect to some purpose (Forrester 1961; Randers 1980; Oliva 2003). The validation process was done following Barlas' (1996) guidelines for model validation. It is worth mentioning that the research done by Robledo (1997) does not provide enough data to make a quantitative assessment of the model ability to reproduce the behavior of the real system. Hence, the model validation is focused on testing the structure consistency of the model. We believe this is valid since the ultimate objective is to increase understanding of the underlying causes responsible for the poor innovation performance of the Colombian capital goods industry.

The structure of the model we built reflects the causal relationships asserted by Robledo as governing the firm's innovation process and the bearing that higher education institutions (HEIs) and government institutions (GIs) have on the accumulation of capabilities at the firm level. Furthermore, when the evidence offered by Robledo was not enough to formalize causality, the equations were built so as to conform to the general knowledge in the literature.

The model parameters have real world counter parts; they are conceptually and numerically valid. Most parameters were estimated using the qualitative description done by Robledo or the literature and surveys related to our research field. Table functions and some parameters values were assumed but checked for plausibility.

The model is robust when subject to extreme shocks and parameters. For instance, zero innovation capability should indicate very few designs in production. This was taken in account during the modeling process; however, we used the Reality Check feature of the Vensim software to test that the model behaves expectedly (Peterson and Eberlein 1994). Not all but some variables were chosen to extreme values.

We consider the model as suitable to investigate how well Robledo's theory accounts for the behavior he sets out to explain.

4.2. Model Results

Before analyzing the model's replication of the reference mode, we consider important to examine what does the expression "vicious circle" (opposed to "virtuous circle") generally describe. Richardson (1999, 79) points out that:

> "The term [vicious circle] actually had its origins in formal logic. Starting from the notion of flawed, circular reasoning, the concept has come to represent an explicitly circular causal process, perceived as characteristically self-perpetuating and self-reinforcing."

One of the central concepts of the system dynamics method is that the system structure is responsible for its behavior. A positive, or self-reinforcing, loop tends to amplify any disturbance and to produce exponential growth (Meadows 1980, 32). Furthermore, a positive loop can also create self-reinforcing decline[2].

Regarding the system we are dealing with in this research, Robledo states the following structural relationship: "capabilities are accumulated within industrial firms,

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[2] This behavior might be produced, as well, by a multi-loop system with dominant positive feedback loops (Richardson 1995).

higher education institutions (HEIs) and government organizations (GIs) through cumulative development processes which depend critically on the interactions between the actors involved" (Robledo 1997, 223). This interdependence is clearly explained by Narula (2002, 795):

> "…the firm –and its innovative activities- are part of a network of other firms and institutions that make up an SI [System of Innovation], and these, ceteris paribus, help determine the firm's behavior …this process is a self-reinforcing mechanism, and can lead to lock-in."

Ideally one would expect to observe the capabilities either grow exponentially or decay exponentially. In other words, the accumulation of capabilities among agents should follow either a virtuous or a vicious cycle. However, as it was quoted early on, Robledo claims that a vicious cycle of accumulation of capabilities is observed when the accumulation stops at a certain level[3].

A system that produces the vicious cycle stated above by Robledo is either a negative loop dominated system or a nonlinear system, at least, composed of two feedback loops (one positive and one negative) linked non-linearly. A negative, or goal-seeking, loop tends to move the system towards an equilibrium point or goal (Meadows 1980, 32). A nonlinear first-order system, for instance, represent a system exhibiting exponential growth at first, but then gradually its growth slows until the system reaches an equilibrium level (Sterman 2000); there are influences that shift the loop dominance between positive and negative loop processes (Richardson 1999, 55). This nonlinear first-order system represent a more realistic situation since no real quantity can grow (or decline) forever. There are always constraints that prevent a self-reinforcing process from expanding itself beyond all bounds (Ricardson 1999, 54).

The behavior of a nonlinear first-order system is not superior or poor per se. However, with regard to the performance of the Colombian industry, the fact that the accumulation of capabilities has stopped at a certain level seems to have a flawed connotation. The level of technological capabilities has not been sufficient to yield a proper economic development. It is in this sense that the system might be caught in a vicious cycle.

The structure of the model we built takes in account the fact that no quantity can grow without any limit. As a result, the model will exhibit neither a pure self-reinforcing growth nor a pure self-reinforcing decline in the accumulation of capabilities. On the contrary, we expect the capabilities to show an S-shaped growth.

In what follows, we present a set of simulations to examine the model's replication of the reference mode. This set of simulations comprises six scenarios. The parameter values changed across scenarios are summarized in table III. In these scenarios the firm's willingness to invest in R&D is influenced by the learning taking place both at the GIs and at HEIs. This learning is perceived by the firm by means of the GIs policy-design effectiveness and the strength of the link between HEIs and firms.

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[3] As it will be mentioned in the next sections, Robledo uses indistinctively two verbal expressions to denote the reference behavior of a "vicious circle".

TABLE III
PARAMETER VALUES FOR SCENARIOS B1, B2, C1 AND C2

Parameter	Scenarios			
	B1	B2	C1	C2
Initial Firm's Innovation Capability	1,0	1,0	1,0	1,0
Initial HEIs' Research Capability	3,0	3,0	6,0	6,0
Initial GIs' Policy-Design Capability	2,5	2,5	6,0	6,0
Quality Target	7,0	10,0	7,0	7,0
Productivity Target	0,3	0,5	0,3	0,3
Capital Growth	15 %	25 %	15 %	25 %
Difficulty to Learn from the Environment	0,3	1,0	0,1	1,0
Degree of Extra-sector Spillovers	0.7	0.7	0.9	0.9

- Behavior under scenarios B1 and B2

Scenarios B1 and B2, although they differ slightly from each other[4], represent the case of a new firm operating in a system of innovation with low initial science and technology capabilities. In other words, the GIs have not accumulated enough capabilities to design the science and technology policies necessary either to encourage business enterprises to carry out R&D investments or to encourage research activities at HEIs.

As we explained earlier, the structure governing the accumulation of capabilities at the firm, HEIs and GIs, is basically composed of two feedback loops. The positive loop represents learning as a cumulative process. The negative loop accounts for the limits to growth as the capability level approaches the 'exploitable capability'. We expect to observe that the low initial research capability accumulated at HEIs and the low policy-design capability accumulated at GIs will neither speed up the learning process governing the capabilities development nor will encourage the firm to invest in R&D early on its life span, thus negatively affecting the firm's overall performance.

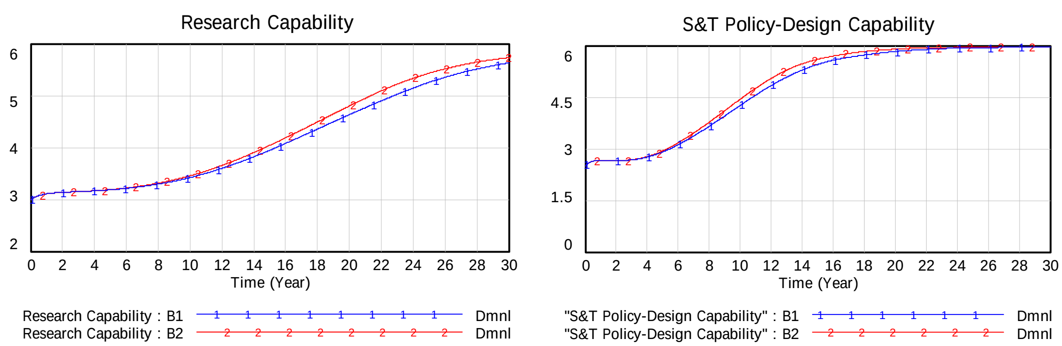

Fig. 5
HEIs' research capability and GIs' policy-design capability under scenarios B1 and B2

At first sight, we observe that both HEIs and GIs manage to increase their capabilities (Fig. 5); the firm also does. There is a lag between the developments of the capabilities under each of these two scenarios. Under scenarios B1, the firm is willing to invest in R&D in year 12; under scenario B2 the firm first invests in year 11. The reason

[4] We will describe the differences among these scenarios along with the description of the behavior obtained.

for this late decision is that both HEIs and GIs fail to accumulate sufficient capabilities in order to encourage the firm to invest in R&D early on its life span. Furthermore, the low level of the firm's innovation capability does not speed up either the development of capabilities at the other agents (Fig. 6).

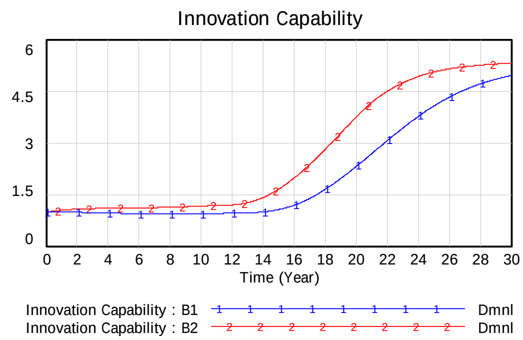

Fig. 6
Firm's innovation capability under scenarios B1 and B2

After the firm starts investing in R&D, the development of the firm's innovation capability takes approximately 4 years under scenario B1 and 3 years under scenarios B2. In fact, during the first 10 years, the positive feedback loop dominates the growth of the firm's innovation capability under scenario B1 causing the innovation capability to decay. Therefore, what or who is responsible for the change in the development path of the firm's innovation capability?

Although the firm is not helping HEIs and GIs to develop their capabilities, the interaction between these two agents enables them to build up their capabilities to and beyond the threshold necessary to encourage the firm, after all, to invest in R&D. Once the firm starts to allocate resources to extend its innovation capability, the positive feedback loop still dominates the capability growth though, on this occasion, it makes the innovation capability to grow. Later on, as the innovation capability approaches its limits to growth, it goes through a nonlinear transition from exponential growth to equilibrium. The negative loop dominates the capability development thus slowing growth down until the innovation capability reaches the maximum quantity. This reference point is given by a constant, the 'exploitable capability', which represents the stock of technological knowledge accessible to the agents making up the system of innovation.

The difference between the assumptions made under scenario B1 and B2 is the higher quality, productivity and capital expansion targets faced by the firm under scenario B2. In addition, the difficulty to learn from the environment is also greater under scenario B2 than under scenario B1. These differences are due to the fact that the firm might have to compete with multinational firms. These firms invest in R&D regardless of the level of capabilities accumulated by the national system of innovation within which the multinational branch operates. In fact, the branch does not necessarily invest in R&D since it can benefit from the investments made in branches located in other countries. Three main issues regarding the model behavior under scenario B2 are worth explaining:

1. Unlike in scenario B1, the firm's innovation capability during the first 12 years does not decay. The capability seems to grow at a decreasing rate; even though it is not possible to determine which loop dominates the behavior. Before year 12 the

firm's innovation capability is higher under scenario B2 than under scenario B1. This is due to the higher technology adaptation effort made under scenario B2 in order to comply with the performance targets. The effort helps to speed up the development of the innovation capability. This advantage in the capability under scenario B2 is amplified by the reinforcing loop representing the learning process. For instance, in year 16, the firm's innovation capability is 1.66 times greater under scenario B2 than under scenario B1. It is reasonably logical to observe a faster evolution of the innovation capability under scenario B2 compared to scenario B1 (see Fig. 6).

2. It is less difficult to learn from the environment under scenario B1 than under scenario B2. We might expect that the firm's environment under scenario B1 will ease the firm's accumulation of capabilities and will cause the firm's innovation capability to increase sooner than under scenario B2. This does not happen. On the contrary, the firm's innovation capability develops fast under scenario B2 (Fig. 6). The reason behind this behavior is that the ease with which learning may occur affects the firm's learning in two ways.

First, the greater the difficulty to learn from the environment, the larger is the marginal impact of the firm's own R&D on the firm's absorptive capacity. In other words the firm's own R&D is critical to the maintenance and development of the capacity to absorb new knowledge. This is a positive effect.

Second, the greater the difficulty to learn from the environment, the less knowledge the firm assimilates of the external knowledge for a given R&D effort. This is a negative effect. Under scenario B2, the positive effect counteracts the negative effect of being within an environment that hinders learning. Hence, the firm's innovation capability develops faster under scenario B2 than under scenario B1.

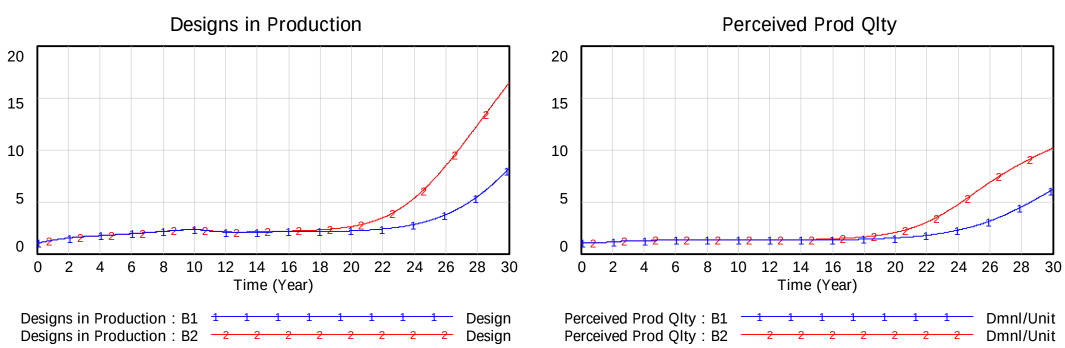

Fig. 7

Designs in production and perceived product quality under scenarios B1 and B2

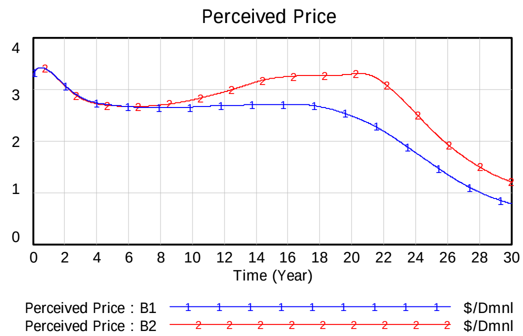

Fig. 8
Perceived product price under scenarios B1 and B2

3. The overall firm's behavior, not only in the accumulation of capabilities but also in the designs in production and the product quality (Fig. 7), is superior under scenario B2 than under scenarios B1. However, the firm's economic performance, surprisingly, is worse under scenario B2. Although the firm develops faster its innovation capability, it does not happen as early as the firm needs it to comply with the demanding conditions of the environment. Since under scenario B2, the quality, productivity and growth (capital expansion) targets are high, the firm has high operational costs. The perceived product price, which is given by the ratio between the product price and the product quality, reflects this fact. The perceived product price is generally no lower under scenario B2 than under scenarios B1 (Fig. 8). For instance, in year 16, the perceived product price is 1.2 times greater under scenario B2 than under scenario B1. The perceived product price is generally no lower under scenario B2 than under scenario B1. Both the EBIT and the ROA also reflect the firm's lower performance (Fig. 9).

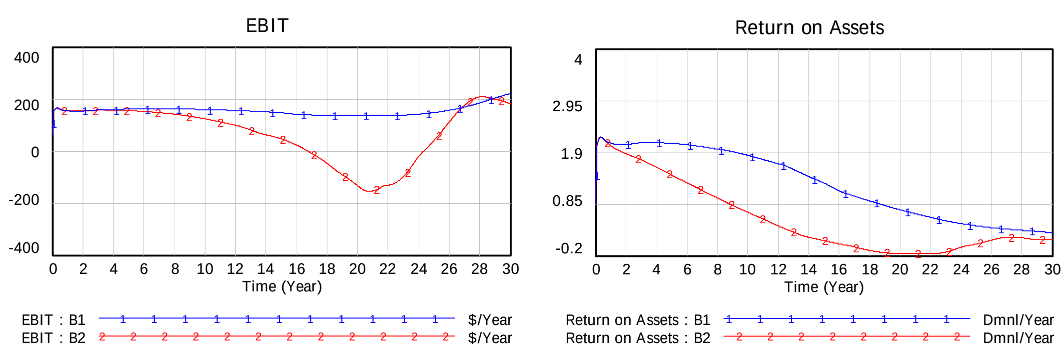

Fig. 9
Firm's EBIT and ROA under scenarios B1 and B2

It follows that a firm that faces high performance standards and operates in a system of innovation with low science and technology capabilities, is at a higher risk to go out of business than if the same firm, embedded in the same environment, has to face less demanding conditions. The sooner the firm is encouraged to invest in R&D the better.

As a final comment, it is worth mentioning that we simulated other scenarios under which the system of innovation has lower innovation capabilities than under scenarios B1 and B2. Under those scenarios, the capabilities of the actors making up the system of innovation decay from their initial values. The rate of acquisition of new knowledge was lower than the rate at which knowledge becomes obsolete. As a result, we neither show nor analyze those scenarios. It is unlikely to observe that the innovation capabilities of the system of innovation decay from the level they already reached.

- Behavior under scenarios C1 and C2

Although scenarios C1 and C2 differ slightly from each other, they represent the case of a new firm operating in a system of innovation with higher initial science and technology capabilities than under scenarios B1 and B2. In addition, the level of spillovers is also higher. This reflects the fact that in a system of innovation with high capabilities, the external benefits received free from research activities taking place at GIs and HEIs is high.

We expect to observe that the accumulation of capabilities at HEIs, GIs and the firm evolves faster and reaches a higher level under scenarios C1 and C2 than under scenarios B1 and B2. The fast development of the HEIs' and GIs' capabilities should encourage the firm to invest in R&D early on its life span, thus positively affecting the firm's overall performance.

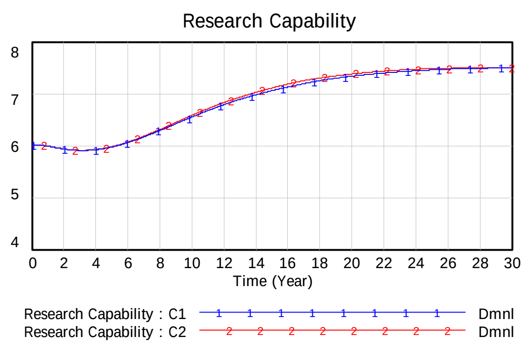

Fig. 10
HEIs' research capability under scenarios C1 and C2

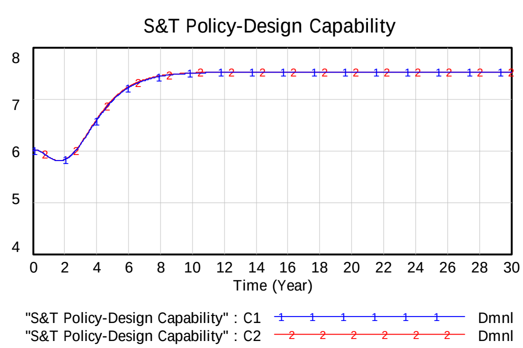

Fig. 11
GIs' research capability under scenarios C1 and C2

Given that, at the beginning of the simulation, HEIs and GIs have accumulated higher capabilities under scenarios C1 and C2 than under scenarios B1 and B2, the accumulation of capabilities unfolds faster. In other words, the technological base necessary for the further development of capabilities is bigger, thus the learning process regulating the accumulation of capabilities evolves more rapidly. The HEIs' research capability reaches the steady state growth -given by the exploitable capability- approximately in year 20 (Fig. 10), which is more than 10 years earlier than under scenarios B1 and B2. The GIs' policy-design capability reaches the steady state growth approximately in year 8 (Fig. 11), which is 8 years earlier than under scenarios B1 and B2.

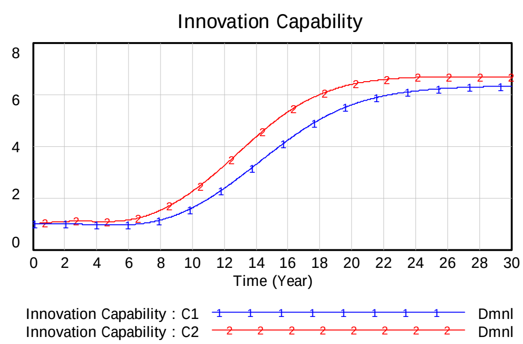

Fig. 12
Firm's innovation capability under scenarios C1 and C2

Surprisingly, the development of both the HEIs' capability and the GIs' capability does not seem to be sensitive to the differences in the firm's innovation capability across the three scenarios (Fig. 12). The interaction between HEIs and GIs is stronger in comparison to both the interaction between HEIs and the firm and between GIs and the firm. As a result, the interaction between HEIs and GIs reinforces the development of their own capabilities independent from the firm's capability evolution. In contrast, the development of the firm's innovation capability does depend on the evolution of the HEIs' and GIs' capabilities.

The fast development of the HEIs' and GIs' capabilities encourages the firm to invest in R&D early on its life span. The firm is willing to invest in R&D in year 3 under the two scenarios. After this, the development of the firm's innovation capability takes approximately 7 years under scenario C1, and 5 years under scenarios C2 (Fig. 12), which is sooner than in the scenarios B1 and B2 explained in the previous section.

There is a lag between the innovation capabilities obtained in each scenario (Fig. 12). During the first 6 years, the positive feedback loop dominates the growth of the firm's innovation capability under scenario C1, causing –as under scenario B1- the innovation capability to decay. This fact does not occur under scenario C2.

The difference between the assumptions made under scenario C1 and C2 is the higher quality, productivity and capital expansion targets faced by the firm under scenario C2. In addition, the difficulty to learn from the environment is higher under scenario C2 than under scenario C1. These differences are due to the fact that the firm might have to compete with multinational firms (like under scenario B2). Three main issues regarding the model behavior under scenario C2 are worth explaining:

1. Unlike in scenario C1, the firm's innovation capability is not significantly reduced before the firm starts investing in R&D. This is due to the higher technology adaptation effort made under scenario C2 in order to comply with the performance targets. The effort helps to speed up the development of the innovation capability. Before year 3 the firm's innovation capability is higher under scenario C2 than under scenario C1. This advantage in the capability under scenario C2 is amplified by the reinforcing loop representing the learning process. It is reasonably logical to observe a faster evolution of the innovation capability under scenario C2 compared to scenario C1.
2. It is less difficult to learn from the environment under scenario C1 than under scenario C2. Under scenario C2, the positive effect counteracts the negative effect of being within an environment that hinders learning. Hence, the firm's innovation capability develops faster under scenario C2 than under scenario C1.

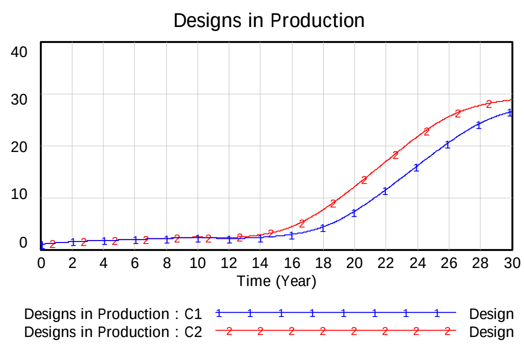

Fig. 13
Designs in production under scenarios C1 and C2

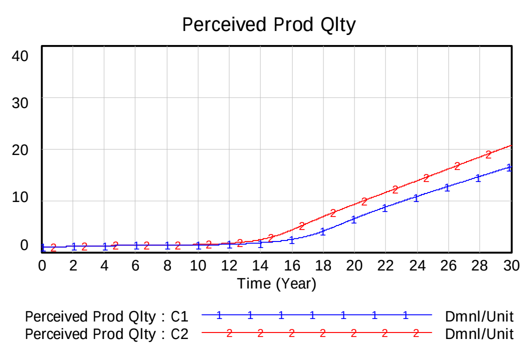

Fig. 14
Perceived product quality under scenarios C1 and C2

3. The overall firm's behavior, not only in the accumulation of capabilities but also in the designs in production (Fig. 13) and the product quality (Fig. 14), is superior under scenario C2 than under scenarios C1. According to the EBIT, the firm's economic performance is worse but it is positive under scenario C2 than under scenario C1 (Fig. 15a). Since the firm has to comply with high quality, productivity

and growth (capital expansion) targets, the firm's operational costs sufficiently rise in the last third of the simulation so as to increase the perceived product price. For instance, in year 24, the perceived product price is 1.62 times greater under scenario C2 than under scenario C1. The perceived product price is shown in (Fig. 15b).

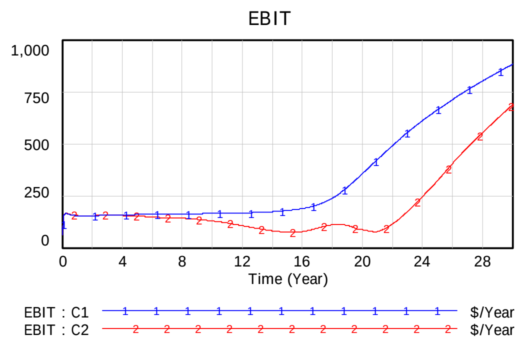

Fig. 15a
Firm's EBIT under scenarios C1and C2

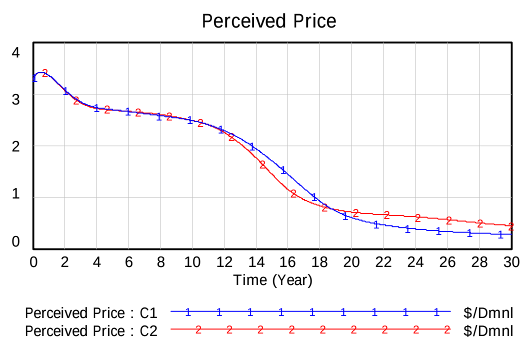

Fig. 15b
Perceived product price under scenarios C1 and C2

Regarding the ROA, the firm's economic performance under scenario C1 is better than under scenario C2 (Fig. 16). This indicates that the earning the firm gets in comparison to the resources that it has at its disposal are lower under scenario C2 than under scenario C1. If the firm has to comply with high performance standards, it is less efficient to generate earnings under scenario C2 than under scenario C1. This might not be the case of every firm operating within a system of innovation with higher initial science and technology capabilities and facing high performance standards. The simulation results we obtained represent the case of a company that has to comply with the performance targets described by the set of parameter values of scenario C2.

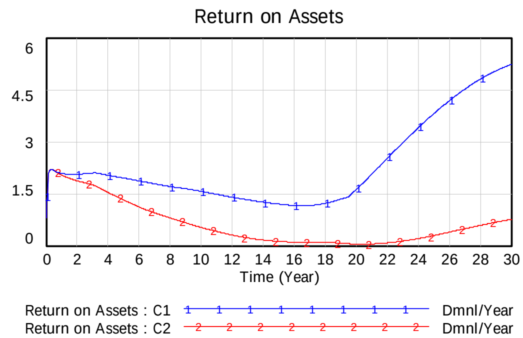

Fig. 16
Firm's ROA under scenarios C1 and C2

- Comparison between scenarios B2 and C2

The overall firm's behavior, not only in the accumulation of capabilities but also in the designs in production and the product quality, is superior under scenario C2 than under scenario B2. The firm's EBIT reflects the firm's superior performance under scenario C2 over the entire simulation time. At the end of the simulation time, when the difference between the firm's EBIT under the two scenarios is greatest, the firm's EBIT is 3.7 times greater under scenario C2 than under scenario B2. The firm's ROA shows that the firm's economic performance is better under scenario C2 just towards the end of the simulation time.

The comparison between scenarios B2 and C2 illustrates that a weak system of innovation, in which neither GIs accumulate sufficient capabilities necessary to design effective science and technology policies nor HEIs accumulate the research capabilities necessary to interact with the industry, will not encourage the private firm to allocate resources to R&D early on its life span. As a result, the firm does not develop its innovation capability either and it is unable to support the development of capabilities at the other agents. It is in this sense that the accumulation of capabilities in the system of innovation is caught in a vicious cycle. This situation has significant economical consequences when the firm copes with high performance standards in the market place. The sooner the firm is encouraged to invest in R&D the better.

5. Research contribution

5.1. It should offer a comprehensive theory

Richardson (1999, 295) claims that "feedback scholars…have in fact argued for formal models on the grounds that even words can be an inappropriate representation, leading to false conclusions about the underlying causes of the behavior of complex systems". Furthermore, as Forrester indicates (1961, 44), "verbal statements need to be clarified by translating them into less ambiguous forms and into a form that will allow us to experiment with the implications of the statements already made".

Robledo forcefully argues that the understanding of the poor innovation performance of the Colombian industry resides in the awareness or decision-making stage of the innovation process. In other words, in the stage in which firms become aware of a problem or an opportunity, and they make either innovation favoring or innovation avoiding decisions.

The value of this research lies in the insights gained by transforming a verbal model into a quantified simulation model with the aid of the system dynamics method. We found that system dynamics serves as a framework to organize and filter knowledge thus leading to a better understanding of complexity. It is in this sense that this research offers an extensive comprehension of both the poor innovation performance of the Colombian industry and its scarce level of the technological capabilities. It is expected that a better understanding of the problem will improve decision making and future policy design regarding R&D.

The qualitative model offered by Robledo points out two important issues: 1. the innovation paradigm influences the willingness of the system of innovation to carry out R&D as a strategic path of development; and 2. the structure of the system of innovation is characterized by the interactions among HEIs, GIs, and the industry. Their interactions comprise four feedback loops and yield the learning process through which the three agents accumulate innovation related capabilities.

As we mentioned, Robledo asserts that innovation favoring decisions will produce a “virtuous circle” of accumulation of capabilities within the system of innovation. In contrast, innovation avoiding decisions produce a “vicious circle” that either prevents the organizations from accumulating capabilities or causes the accumulation to stop at a certain level[5]. Furthermore, the level of capabilities influences the R&D decision itself.

Robledo refers indistinctly to two different patterns of behavior when the accumulation of capabilities is governed by the “vicious circle”. It follows that it is either trivial to distinguish them as different patterns of development and Robledo uses the expression “vicious circle” just to denote a general closed loop of causal influences, or it is difficult to infer the emergent behavior of the intertwined relationship among the system’s agents. In either case, the need to translate verbal statements into a less ambiguous form is obvious. As they are expressed by Robledo, the verbal expressions characterizing “vicious circle” in the accumulation of capabilities leave open questions such as: Under which conditions each pattern of behavior takes place? Are they produced by the same underlying structure? Which reasons confer a flawed connotation to either pattern of behavior? The translation of a verbal model into a formal model forces us to make a distinction between the two types of behavior and to determine the structure originating them.

As mentioned earlier in this paper, with the aid of the system dynamics method, we identified the following issues regarding the relationship between structure and behavior:

- A positive, or self-reinforcing, loop produces exponential growth and can also create self-reinforcing decline. Thus, both a virtuous and a vicious cycle can be produced by a positive feedback loop.
- The accumulation of a quantity that stops at a certain level, is produced either by a negative loop dominated system or a nonlinear system, at least, composed of two feedback loops (one positive and one negative) linked non-linearly. For instance, a nonlinear first-order system displays S-shaped growth and represents a more realistic situation than a positive dominated loop, since no real quantity can grow (or decline)

[5] Although Robledo uses indistinctly both sentences to denote the emergent behaviour of a vicious cycle, we adopt the second expression “accumulation stops at a certain level” as the reference mode of the vicious cycle (see chapter 3). The reason to have chosen the second expression is that Robledo uses it more often than the first one.

forever. Nonetheless, the behavior of a nonlinear first-order system is not superior or poor per se.

With regard to the innovation performance of the Colombian industry, it is not plausible to observe neither pure exponential growth nor pure exponential decay in the accumulation of innovation capabilities. There are factors that constraints a self-reinforcing process from expanding the accumulation of capabilities beyond all bounds either linked to a developing economy, such as the accessibility of information and the educational level, or akin to the properties of knowledge such as tacitness and obsoleteness. As a result, the structure of the model we built takes in account the fact that no quantity can grow without any limit.

We consider that both the pace of and the limits to growth in the development of capabilities are the reasons that confer a flawed connotation to the evolution of the innovation related capabilities of a system of innovation. In the Colombian case, both the pace and the level reached by the technological capabilities have not been sufficient to yield a proper economic development of the industry. It is in this sense that the system might be caught in a vicious cycle.

To finish off, it is important to mention that Robledo does not define a clear time frame for the perception of the problem. This time frame is crucial for the problem assessment and analysis. For instance, regarding the non-linear system underlying the accumulation of capabilities, we can observe pure exponential growth if the time horizon is sufficiently short so as to prevent us to perceive how the capability growth slows down as the capability approaches its maximum value. Furthermore, we can witness a stagnant development of capabilities just after the learning process was initiated. The formalization of the verbal model made necessary the definition of a time horizon.

5.2. It should improve the understanding of the problem

Robledo defines innovation as a learning process that benefits not only from the firm's internal learning process underlying the accumulation of capabilities but also from the firm's interaction with HEIs and GIs. Furthermore, he asserts that the low level of innovation capabilities accumulated by the Colombian industrial innovation system, the fact that firms are not willing to invest in R&D and the interactive learning regulating the accumulation of capabilities are inhibiting the further development and accumulation of innovative capabilities.

This thesis illustrates that the low level of innovation capabilities accumulated within the system of innovation is actually delaying its own development. As a result, the threshold of accumulated capabilities at HEIs and GIs needed in order to encourage the private firm to invest in R&D might take decades to be reached, as we showed in the previous sections. This fact is indirectly suggested by Narula (2002, 798) when he discusses about the linkages among the actors of a system of innovation:

> "Such linkages [linkages within the SI] are both formal and informal, and will probably have taken years –if not decades- to create and sustain."

Although the low level of capabilities has delayed its own development, the learning process underlying the accumulation of capabilities is currently taking place. As we examined with the different scenario simulations performed, the positive loop dominating the early development of capabilities has the ability to amplify any disturbance or any initial capability developed by the system of innovation.

Robledo concludes that a minimum level of capabilities is required for the virtuous cycle of development to gain momentum. This fact was clearly observed in the simulations. Unless none capability has been accumulated in HEIs or GIs until the present time, the interactive learning between the firm, HEIs and GIs will necessarily trigger the development of their capabilities. If the system of innovation has accumulated little capabilities so far, the further development of capabilities will evolve at a very slow pace. As a result, when the level of capabilities will be sufficient to encourage the firm to invest in R&D, it might be late and probably the firm will have not survived in the meanwhile, since it failed to develop the capabilities necessary to compete in the market.

In addition, we found that among the four feedback loops that, according to Robledo, govern the interactions among HEIs, GIs, and the industry, the interaction between HEIs and GIs is stronger in comparison to both the interaction between HEIs and the firm and between GIs and the firm. As a result, the interaction between HEIs and GIs reinforces the development of their research capability and policy-making capability independent from the firm's capability evolution. In contrast, the development of the firm's innovation capability does depend on the evolution of the HEIs' and GIs' capabilities.

The fact that the interaction between HEIs and GIs reinforces the development of their own capabilities rather independent from the firm's capability evolution reflects the crucial role that they have to play in the firm's innovation process. However, this is not consistent with the conclusions attained in the literature regarding the system made up by government, HEIs and industry. According to the literature on the triple-helix model of university, industry, and government relations (Etzkowitz and Leydesdorff 2000), every actor plays a key role in the innovation process. In fact, in some cases each actor can take the role of the other despite the different tasks they have to perform.

The actors that make up the system of innovation have to be aware not only of the role they play in the interactive learning regulating the accumulation of capabilities but also of the inertia embedded in the learning process itself. The role that HEIs and GIs have to play in the firm's willingness to invest in R&D is crucial, as well as the support – through policies- that they have to give to firms in order to sustain the firm's willingness to invest in R&D until a long time has elapse and the firm gets the benefits from their investments in R&D. This fact reflects one of the conclusions reached by Robledo (1997, 348), as he denotes it:

> "The need for a learning approach to innovation and technological change must be recognized by key actors of the innovation process (industrialists, academics and policy-makers). The obvious condition to learn is to recognize the need to do so and to be willing to make the sustained efforts that learning requires".

In addition, the actors have to understand that the system interdependence is not "good" or "bad" per se as long as every actor is aware of the system structure and its own role. Each actor has to understand that within a system of innovation not only the benefits of accumulating capabilities spill over the other actors, but also the negative aspects. A better understanding of the system structure is clue for a more efficient policy-design (Sterman 2000; Forrester 1994). This is particularly important for the Colombian system of innovation since, as Robledo claims, there are inherent time lags in conveying the insights of innovation analysts to policy-makers making up the system.

We consider that if innovation is a learning process closely linked with the development of capabilities different to those necessary for the production process, it is logical to observe that the firm will fail to develop any capability to support innovation unless it makes direct investments in R&D. In reality, and relating this research to other studies regarding the technology dependence of developing countries, we found a key explanation or verification of previous conclusions reached in the literature (Mytelka 1978; Buckley 1979; Contractor 1983; Pack and Westphal 1986; Nelson and Pack 1998; Hansen et al 2002). When a firm is unable to innovate it has to license products developed else where. As a result, the firm does not have the possibility to develop the capability necessary to neither produce the products already licensed nor to improve their quality. Furthermore, in case that it is cheaper to pay for licenses than investing in R&D, the firm will stay far from the possibility to develop the capabilities necessary not only to develop new products but also to interact with the GIs and HEIs. The sooner the firm is encouraged to invest in R&D the better; actually this is even more convenient if the firm has to comply with high performance standards.

As a final comment, we pointed out in the previous sections that the delay between the time that R&D investments take place and the time when direct benefits are perceived is significant. As a result, we recognizes that given the intangible nature of capabilities and its effect on the innovation process, the actors making up the system of innovation maybe reluctant to invest in R&D. This fact highlights that industrialists, academics and policy-makers need to do both acknowledge that innovation is a learning process and estimate the intangible benefits of R&D.

5.3. It should increase the accessibility of Robledo's research

Although the relationship between R&D and economic development is highly unquestioned (Forester 1994; Solow 1994; Romer 1994; Aghion and Howitt 1999), the attributes of that relationship is a matter not yet clarified. Based on the research done by Robledo (1997) we established an initial formal model of the underlying causes explaining the poor innovation performance of the Colombian capital goods industry and the role played by Higher Education Institutions (HEIs) and the Government Institutions (GI) in the process of accumulation of innovation capabilities. By proposing formal relationships between the variables making up the verbal description of the problem we leave the relationships exposed to be questioned by other researchers beyond the qualitative statements. As said by Forrester (1994, 63), "assigning a number does not alter the accuracy of the original statement, but it does create a much more explicit basis for communication".

Likewise, this first formal representation of the research done by Robledo could be questioned by the actors that make up the system of innovation itself - industrialists, academics and policy-makers. They could examine the assumed relationships among the structure components and judge their plausibility. They could add also dynamics or assumptions that were omitted by both Robledo and us. Hence, this research might help to attain one of the purposes of Robledo's research: to highlight the roles that firms, HEIs and the government have to play in the performance of the system of innovation. This might be also the first step to improve policy-design regarding science and technology.

To finish off, this study suggest that a careful analysis of an existing theory can be very generative, helping to test and extend verbal theories and provide new explanations for empirical results about the complex phenomena of innovation within a developing economy.

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