# Capacities, Processes, and Feedbacks: The Complex Dynamics of Development

**Gabriel Yoguel** * and **Verónica Robert**

The theory of complex systems applied to the evolutionary economics allows innovation to be considered not only the result of the intentional action of individual agent, but as an endogenous property of system dynamics. In this sense, innovation constitutes an emergent property of the system because it is not entirely determined on micro or macro levels, but is a result of continuous interaction between the two. At micro level the paper assumes that economic agents are endowed with intentionality in their adaptive or creative reactions that explains specific patterns of capacities and connectivity development. At macro level, processes of creative destruction, appropriation and structural change describe the evolution of the whole system. These dynamics tend to consolidate institutional frameworks that could be adverse or beneficial to innovation and that would reinforce divergent development paths. The feedbacks between micro and macro levels explain why the initial differences in development levels tend to increase between developed and developing countries.

*Keywords*: Complexity, Absorption capacity, Connectivity, Innovation

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* Corresponding Author, Professor, Instituto de Industria (Idel), Universidad Nacional de General Sarmiento (UNGS), Juan M. Gutiérrez St. 1150 (B1613GSX), Los Polvorines, Buenos Aires, Argentina, (Tel) +54-11-4469-7567, (Fax) +54-11-4469-7551, (E-mail) gyoguel@ungs.edu.ar; Assistant Professor, Instituto de Industria, Universidad Nacional de General Sarmiento, Juan M. Gutiérrez St. 1150, Los Polvorines, Buenos Aires, Argentina, (Tel) +54-11-4469-7567, (E-mail) vrobert@ungs.edu.ar, respectively. This paper has been presented in the 17th SJE-KERI-KIF-CEC International Symposium New Ways for Growth and Catch-up in a Changing Global Environment in October 16, 2009. We thank the comments of Keun Lee and the two discussants, Jaymin Lee and Elias Sanidas in this seminar. We also thank the comments of Cristiano Antonelli and Mario Cimoli to previous versions of this paper. The usual disclaimers apply.
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## I. Introduction

The overall objective of this article is to analyze some features of countries with different levels of development using the complex systems approach applied to innovation economics (Silverberg, Dosi, and Orsenigo 1988; Dosi 1991; Dosi and Kaniovski 1994; Dosi and Nelson 1994; Foster 1993, 2005; Witt 1997; Metcalfe, Foster, and Ramlogan 2006; Frenken 2006; Antonelli 2007). Taking complex systems as a framework allows us to understand the morphology and dynamics of innovation systems characterized by (i) heterogeneity of creative agents endowed with intentionality and different abilities for building competencies and linkages, (ii) temporal irreversibility, as a result of a dynamic driven by a non-ergodic path dependence, (iii) disequilibrium and non-linear interactions among agents in a multidimensional space, and (iv) the presence of institutional rules.

As was pointed out "an innovation economics approach to complexity thinking makes it possible to overcome the limitations of both general equilibrium economics and evolutionary analysis into a system dynamics approach" (Antonelli 2009, p. 8). This is the case because for neoclassical theory innovation is not part of the economic process, and for the evolutionary approach innovation is formalized through stochastic processes and then remains exogenous (Nelson and Winter 1982). The theory of complex systems applied to the evolutionary vision of the economy allows innovation to be considered as an endogenous property. According to the central ideas of this paper, innovation is not only the result of the intentional action of each individual agent, but is also the endogenous product of system dynamics. In this sense, innovation constitutes an emergent property of the system because it is not entirely determined on micro or macro levels, but is a result of continuous interaction between the two. In this paper we use the idea that agents are endowed with intentionality in their adaptive or creative reactions to understand how the differences in creative and adaptive reactions of heterogeneous agents lead to the emergence of specific patterns of innovation and growth that explain the differences between developed and developing countries. In turn the presence of non-linear dynamics involved in learning paths explains why the initial differences in development levels tend to increase. These dynamics tend to consolidate institutional frameworks (macro and meso structures) that are adverse or beneficial to innovation and that reinforce divergent development paths (Rivera Ríos, Robert, and Yoguel 2009; Hoff and Stiglitz 2002; Aghion, David, and Forey 2008). The institutional framework is itself an emergent property, because it is the combined result of interactions between heterogeneous agents, in terms of behaviors, skills and connections, and the structural conditions described by appropriation (Cohen, Nelson, and Walsh 2000; Antonelli 1997, 2007; Winter 2006; Dosi *et al.* 2006; Pisano 2006; Teece 1986; Erbes *et al.* 2006), destructive creation (Schumpeter 1912, 1942; Metcalfe 2002; Metcalfe, Foster, and Ramlogan 2006), and structural change processes (Ocampo 2005; Ross 2005; Reinert 2007; Palma 2005; Cimoli *et al.* 2005).

Within this analytical framework, we conceive an innovation system as a complex system whose components — organizations, whether firms or institutions — interact and learn to develop their absorption (Cohen and Levinthal 1989; Zahra and George 2002) and connectivity capacities (Norman 2002; Cullen 2000; Grandori and Soda 1995), which define the architecture of connections. The interactions between a system's components trigger changes in its capacities. That means that firms' capacities reinforce themselves through feedback mechanisms, then capacities and connections evolve over time. Together, capacities and feedback mechanisms lead firms to undertake different innovation efforts. However, the results of these efforts not only depend on the firms' behavior but also on the macro and meso dynamic. This dynamic can be characterized by the processes of creative destruction, appropriation, and structural change, which define whether the institutional framework is conducive to innovation or not. As a consequence of the interaction between these processes and the firms' capacities mentioned above, innovation emerges endogenously. We assume that the levels of absorption and connectivity capacities, the feedback mechanisms between them and the characteristics of the meso and macro structure defined by the three processes and the institutional framework could help to differentiate developing and developed countries.

The main questions of this paper are as follows. Why do different innovation patterns emerge in developed and developing countries? What characterizes the micro interactions (the development of absorption and connectivity capacities and feedback mechanisms between them) in developed and developing countries? What characterizes the processes of destructive creation, appropriation and, consequently, structural change in developing countries? How do these specificities work in order to explain the way firms react? Finally, in which cases do system dynamics lead to an adverse institutional framework that limits the interactions of creative actors and the generation of positive feedbacks and knowledge spillovers? In addition to all these theoretical questions, we wondered if the available empirical evidence on absorption and connectivity capacities would allow developed and developing countries to be differentiated.

In order to answer all these questions, and following Antonelli (2007), we depart from the idea that the reactions of agents can be both creative and adaptive. Although we assume that agents are able to extend both types of reactions, in developing countries adaptive reactions stand out. We propose that in these countries a productive and commercial specialization profile based on goods intensive in the abundant factors will prevail, which lead to a lock-in in their development path. To escape from this lock-in requires creative responses in the whole system. These creative responses begin with the existence of a critical mass of agents playing against the rules, which help transform the institutional framework. Playing against the rules means intentional creative reactions of agents that threaten the technological, organizational, and institutional conditions on which quasi-rents are generated. This means not only promoting the creative destruction process but also the appropriation and structural change processes. Therefore, the lack of this critical mass blockades the development of positive feedbacks, externalities, increasing returns, and therefore the development of the three processes mentioned. We assume that in developing countries there are agents that play against the rules, but there are not enough of them to change the specialization pattern and the main characteristics of meso and macro dynamics. According to North (1993) and Hoff and Stiglitz (2002), endogenous or exogenous shocks are needed to bring about changes in the institutional framework. We assume that the success of these shocks will depend on the existence of a critical mass of agents playing against the rules.

In this paper we also provide some empirical support for these ideas by discussing a set of papers that try to explain the relationship between firms' capacities, connectivity, innovation, and competitiveness, which means the feedbacks and non-linearities present in the learning path. A set of stylized facts for countries with different levels of development can be derived from this literature.[1] We also explore the litera-

[1] For developing countries, see Erbes, Robert, and Yoguel, Forthcoming (2010); Albornoz, Milesi, and Yoguel (2005); Arza and López (2008); Benavente and Contreras (2008); Bianchi, Gras, and Sutz (2008); Cimoli, Primi, and Rovira

ture and some statistical data that help describe the main features of appropriation, creative destruction, and structural change in developed and developing countries (Cimoli, Porcile, and Rovira 2010; Rivera Ríos, Robert, and Yoguel 2009; Reinert 2007). By presenting this evidence we try to shed light on how complex relations between capacities and processes evolve over time and how emergent properties are generated, especially those related to innovation, institutional frameworks, and development (Cimoli, Porcile, and Rovira 2010).

The rest of the paper is structured as follows. The first section introduces the complex systems approach and its specificity to the study of innovation economics and development issues. The second section presents an analytical model that explains the self-reinforcing dynamics between absorption and connectivity capacities and between capacities and innovation. We will argue that the presence and intensity of this feedback impacts on the improvement of creative destruction processes, appropriation, and thus on structural change and economic development. In turn, these macro and meso dynamics also influence the capacities of economic agents. After presenting in the third section the specificities of this analytical model in developed and developing countries, the fourth presents a review of the literature on capacities and linkages in developed, developing and newly industrialized countries. Finally, the fifth section deals with the main findings and some policy issues related to this approach.

## II. Theoretical Framework Based on a Complex Systems Approach

The complex systems approach applied to economics and especially to innovation economics has grown enormously during the last few

(2008); Crespi (2008); Garrido Noguera and Padilla-Pérez (2008); Kupfer and Avellar (2008); Lugones and Suárez (2006); Roitter *et al.* (2007); Yoguel (2007); Albornoz and Yoguel (2004); Marin and Bell (2006); among others. For developed countries, see Hakansson and Snehota (1989); Kleinknecht and Reijnen (1992); Teece (1992); Andersen and Cantwell (1999); Alm and Mckelvey (2000); Bidault, Despres, and Butler (1998); Coombs and Metcalfe (2000); Tether (2002); Monjon and Waelbroeck (2003); Caloghirou, Kastelli, and Tsakanikas (2004); Negassi (2004); Laursen and Salter (2004); Belderbos, Carree, and Lokshin (2004); Veugelers and Cassiman (2005); Vega-Jurado *et al.* (2008); D'Este and Neely (2008). Finally, for new industrialized countries, see Eom and Lee (2008); Tsai and Wang (2009); among others.

decades. Although most of these works were applied to developed economies, some of the main questions of development may be tackled from a complex dynamics perspective. In the late 1960s, Simon (1969) introduced, from a static perspective, the notion of the architecture of complexity to economics and modular systems. This stresses the existence of hierarchy and differential relationships between and within modules of an economic system, and especially the idea of simultaneous interactions between micro and macro dimensions. During the 1980s, the idea of self-organization, linked to the study of technological diffusion and competing technologies, was introduced by several authors that emphasized the historical time and the heterogeneity of agents in terms of capacities and strategies (Silverberg, Dosi, and Orsenigo 1988; Arthur 1989).

Since then, different authors linked to the Schumpeterian legacy (Antonelli 2007, 2008; Metcalfe 2007; Dosi 1991; Dosi and Kaniovski 1994; Dosi and Nelson 1994; Foster 1993, 2005; Saviotti 2001; Witt 1997) have been using the complex systems approach to explain several aspects of innovation economics within the framework of variation, selection, and retention mechanisms which would account for the relationship between innovation and the processes of creative destruction and structural change. From this perspective, the factor that best explains the evolution of an economic system is the generation of micro-diversity from innovative processes that change agents' routines by interacting in a nonlinear way in conditions of disequilibrium.[2] The idea that brings this group of authors together is that according to them the complex systems approach helps to understand the dynamic nature of economic systems as highlighted by Schumpeter. Therefore, different evolutionary and neo-Schumpeterian economists have introduced complex systems to explain (i) the evolution and dynamics of a capitalist system as an open-ended process of qualitative change led by innovation, as Schumpeter remarked (Fagerberg 2003); and (ii) the structural changing and self-organizing nature of capitalism, which concerned Marshall. From the latter perspective, Antonelli (2007, 2008) and Metcalfe (2007) also explain the differential dynamics of production systems on the assumption that heterogeneous agents have creative reactions. In particular, from Antonelli's perspective, intentional behavior[3]

[2] As part of the Schumpeterian and Penrosean traditions, some authors, like Foster (2005), argue that the biological metaphor is not the most useful one for discussing the specificities of economic systems.

explains innovation as an emergent property. Nevertheless, other authors emphasized use the complexity approach to account for long waves of economy (Silverberg 2003), economic growth (Metcalfe, Foster, and Romlogan 2006) and changes in technological paradigms (Lane Forthcoming 2011), following, among other, the ideas of self-organization, far-from-equilibrium dynamics, emergency and self-organized criticality (Prigogine and Stengers 1985; Kauffman 1993; among others).

Other group of authors, linked to the economic perspective of the Santa Fe Institute (Arthur, Durlauf, and Lane 1997; Lane and Maxfield 1997; Lane 2011; among others), has focused on the study of economics as an out-of-equilibrium evolving complex system. In this case, the emphasis is on the self-reinforcing mechanisms that may even work at an institutional level. Those authors are mainly concerned with (i) non-linearities and positive feedbacks emerging from increasing returns, (ii) the analysis of adaptive complex systems using the biological metaphor (Holland 2004) and (iii) the history of technology (David 1985; Lane and Maxfield 1997). In these cases, they are interested not only in explaining innovation economics and technological change, but also finance topics and macroeconomic dynamics, without abandoning some neoclassical assumptions.[4]

Computational simulations of the Agent Based Modeling type and evolutionary games are frequently used as tools for applying complex systems theory to economics.[5] These models are used to understand innovation economics[6] through a neoschumpeterian approach (Silverberg, Dosi, and Orsenigo 1988; Dosi 1991; Dosi and Kaniovski 1994; Dosi and Nelson 1994) and from the perspective of the Santa Fe Institute (Arthur 1999; Arthur, Durlauf, and Lane 1997; Testfastsion 2003).

[3] Antonelli (2007) stresses that the intentional *rent-seeking* agents' behavior plays a key role in the analysis of economic dynamics. Within this conception, agents are not automata as they are usually taken into account in computational complexity and in other attempts to apply this approach to economics.

[4] Some authors like Colander (2009) and Perona (2004) propose that it is likely that complex systems will become a kind of nexus between orthodox and heterodox thinking in economics. We do not agree with this argument because there are differences in ontological assumptions that can not be reconciled simply by using the same formalizing tool.

[5] Among these models, those based on differential equation systems can be differentiated from those that use cell automata.

[6] Outside of innovation economics, these models have a multiplicity of applications from financial market analysis, macroeconomics of disequilibrium, to the study of agents' expectations.

Others authors linked to the development of a theory of inventions (Lane Forthcoming 2011; Fleming and Sorenson 2001) use fitness landscape models. Some authors consider that the physical percolation model helps understand the complex dynamics of technology adoption (Silverberg and Verspagen 2005; David and Foray 1994; Antonelli 1997). Finally, authors that focus their analysis on networks and interactions (Cowan 2004) have been especially interested in methodological tools derived from the study of economic and social networks (Barabási and Albert 1999; Watts 2003). Nevertheless, evolution is barely touched upon in this approach.

A common thread among the authors that use the complexity approach to analyze innovation is that they set aside the classical mechanics which have inspired neoclassical economic theory since the Walrassian general equilibrium model. Therefore, all these authors characterize complex systems by taking into account features such as irreversibility, uncertainty, spatial and temporal organization, and heterogeneity of system components. By introducing the idea of complexity to economics, these authors account for a set of contributions from other disciplines such as physics, chemistry, and biology, which in turn are fed by mathematical modeling (including non-linear dynamics, strange attractors, and agent-based simulations) developed in recent decades. Based on these issues, a complex system is characterized by a set of dimensions that include: (i) the adaptive learning and interaction with the environment, (ii) positive feedback, (iii) emerging properties (macro-structure dynamics explained on the basis of local interactions at the micro level), (iv) ontological uncertainty, (v) the creative capacity of the system components, and (vi) the existence of order out of equilibrium (attractors).

In this regard, Metcalfe, Foster, and Ramlogan (2006) emphasize the idea that the complex systems approach can account for some key elements of economic systems, which conventional economic theory has sidelined by resorting to the notion of equilibrium. This approach differs from the arguments supported by traditional economic theory in which equilibrium is considered an optimum state that requires the existence of perfect connections between system components, which implies the assumptions of perfect information (Foster 2005).[7] Thus, contrary to

[7] According to Foster, a dissipative complex system itself organizes exchanges of knowledge with the environment, which reduces losses of entropy through an activity of human creativity.

expectations of conventional economics, the equilibrium of a system is seen, according to complex systems theory, as a situation of disorder and minimal coordination.

Some authors from the Santa Fe Institute also depart from the idea that complex systems can generate order from the interactions of decentralized and dispersed agents. Furthermore, since complex system dynamics are essentially open-ended, the idea of a global optimum is useless by itself. Therefore, the notion of a steady state should change with the concept of evolution (Durlauf 1997). "Because new niches, new potentials, new possibilities, are continually created, the economy operates far from any optimum or global equilibrium. Improvements are always possible and indeed occur regularly" (Arthur, Durlauf, and Lane 1997). Therefore, the relevance of complex systems is that this approach can account for some traits of economic systems, such as irreversibility, path dependency, and the presence of increasing returns in which non-linear dynamics and positive feedback mainly occur (Arthur 1999).

The features of non-ergodic[8] path dependence (Antonelli 2007) explain why complex systems are not only sensitive to initial conditions, but also to disturbances occurring along their path, which leads to a diversity of patterns of behavior in the long-term dynamics that affect the overall system (Dosi and Kaniovski 1994; Antonelli 2007). In this sense complex systems help to understand why initial differences might increase over time rather than decline, as the neoclassical hypothesis of convergence suggests.

Following Antonelli (2008), we consider the relevance of regarding innovation as an emergent property of a complex system. This property is the result of the intentional creative reactions of agents and their ability to change the architecture of interactions, which are endogenous consequences of the localized action of agents. Creativity is an essential feature of adaptive complex systems (Kauffman 2003). However, the intentionality of economic agents is the distinctive characteristic of the complex systems in which human beings are involved. Foster (2005)

[8] This kind of path dependence occurs when small shocks at any given time affect the trajectory of long run in a meaningful and irreversible way (Arthur 1989 and Prigogine and Stengers 1998). It occurs when trajectories emerging from points coming away from each other exponentially (nonlinear) over time. Thus, "minor differences, insignificant fluctuations may, if they occur in appropriate circumstances, invade the whole system, engender a new operating system."

also pointed out the importance of intentionality and agents' creative capacities when he considered interactions not only between agents but also between their mental models.

Absorption and connectivity capacities are key dimensions in understanding both the intentional creativity of agents and their architecture of linkages. The effects of feedback mechanisms between these capacities aid understanding of the non-linear dynamics of learning processes. We propose that a complex system can be conceived as a mechanism for generating order from the reinforcement of absorption and connectivity capacities and between these and the innovation process. The emergent order from micro interaction is one of the most frequently highlighted properties of complex systems. Therefore, innovation emerges from interactions between the absorption and connectivity capacities of creative agents within the framework of specific dynamics in the processes of appropriation, creative destruction and structural change. In this regards, the view of complexity used in the chapter is in agreement with the idea that the complex systems approach applied to innovation economics allows economic evolution to be understood as an ordered macro structure that evolves according to dispersed, decentralized micro interaction that, in turn, is affected by the macro dynamics in which it is involved.

This paper puts forward that a complex system can be conceived as a mechanism for generating order from the absorption and connectivity capacities of its components. Introducing these capabilities into the analysis leads to a ranking of orders of complex systems. This chapter shows a parallel between higher orders of complexity and higher degrees of development of a productive structure. The complex systems of higher orders would require greater absorption and connectivity capacities, which allow access to the skills generated in the multidimensional space in which they operate.

We assume that the components of the system are firms and other institutions and organizations like chambers of commerce, consultancies, universities and technological centers, among others. These are endowed with different capacities that lead to creative or adaptive reactions. The firms and institutions are embedded in different systems and networks where they build their architecture of linkages that involves non-exclusive commercial relations but also long-term relationships with other agents. These systems and networks that firms belong to constitute the multidimensional space described by Antonelli (2008). Clusters (Humphrey and Schmitz 2002), local systems (Camgni 1991; Becatini

1989); sectoral systems of innovation (Malerba and Orsenigo 1997), production networks (Albornoz and Yoguel 2004; Erbes *et al.* 2006; Bisang *et al.* 2005; Yoguel 2007), global value chains (Humphrey and Schmitz 2000; Greffi 2001) are successful historical forms of the spaces where firms build their capacities and interact. Nevertheless, the degree of development of those spaces in terms of the importance achieved by the generation, circulation and appropriation of knowledge (both tacit and codified) involves a variety of situations ranging from the most virtuous to the weakest. This variety depends on the capacities of firms and institutions, the importance of agents with creative reactions that play against the rules[9] and the development of creative destruction, appropriation and structural change processes. Therefore, this space of interaction will have different attributes in countries with different levels of development. This multidimensional space is different to the attributes of the firms and institutions that comprise it and therefore lies in a mesoeconomic dimension and cannot be reduced to the sum of its parts. This feature stems from the feedback between the absorption and connectivity capacities of agents, which justifies applying the complexity approach.

Therefore, beginning with the existence of feedback mechanisms between the absorption and connectivity capacities of agents that determine the innovation process, the main hypotheses of this paper highlight some differential characteristics in developed, developing and newly industrialized countries. These differences are manifested in: (i) the development of absorption and connectivity capacities of agents; (ii) the relevance of feedback effects between them; (iii) the importance of the absorption and connectivity capacities to determine the innovation and (iv) the relationship between the dynamics of the macro and meso structure and agents' capacities. Therefore, our aim is to understand the learning process as a non-linear one explained by feedback between competencies and linkages in order to identify constraints that may exist in developing countries, which limit the generation of agents' capacities and processes. The following sections define these capacities and processes. They will deal with their interactions as well as their impact on economic development.

[9] That involve bridge institutions (Casalet 2005), gatekeepers (Giuliani and Bell 2005), club goods, diversity and the possibility to establish complementarities, among other.

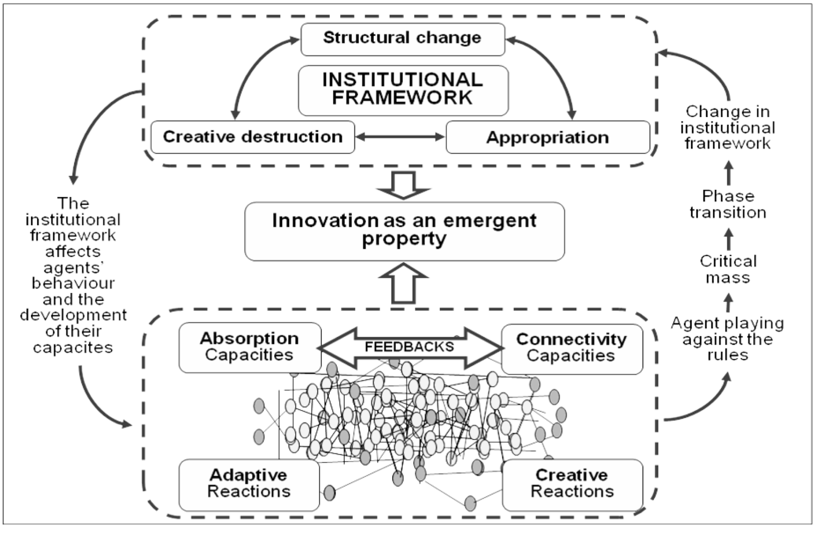
## III. Feedback between Absorption and Connectivity Capacities: Innovation and Structural Change

This section proposes a theoretical model that accounts for the interaction between creative agents and the development of capacities and processes built upon those interactions. Departing from the theoretical framework described in the previous section, we argue that innovation can be seen as the result of non-linear dynamics in a learning process driven by mutual reinforcement between absorption and connectivity capacities within the specific dynamics of the processes of creative destruction, appropriation and structural change (see Figure 1).

The absorption capacity of the system can be regarded as the ability to recognize new external information, assimilate this and apply it (Cohen and Levinthal 1989). This capacity is not only related to the possibility of accessing existing knowledge in the multidimensional space, but also implies the ability to identify useful knowledge and generate new knowledge. As a result, absorption is not an ability that can be automatically developed nor is it equally accessible to all systems. Rather, it requires the development of skills within the previous evolutionary path of the system. In this sense, it can be assimilated to the ideas of routines (Nelson and Winter 1982), dynamic capabilities (Teece and Pisano 1994) and endogenous skills (Roitter *et al.* 2007). As long as this capacity is developed, creative reactions will predominate over adaptive ones.

The multifaceted approach we use to evaluate absorption capacity is in response to a mismatch between the very rich theoretical definition of this capacity and a generally simplistic attempt to estimate it which only considers R&D spending (Cohen and Lenvinthal 1989; Zahra and George 2002). Therefore, absorption capacity can be defined in terms of work organization and learning processes, quality management, and the extent of embodied and disembodied innovation activities, among other variables (Zahra and George 2002; Cullen 2000; Coriat and Weinstein 2002; Roitter *et al.* 2007). Therefore, connectivity capacity refers to the agents' ability to establish the architecture of connections and then make changes in the multidimensional space. It requires creative reactions, which in turn are constrained by the dynamics of macro and meso structure.

Connectivity capacity is associated with the system's potential for establishing relationships and generating interaction with other agents




Source: Own elaboration on base Lewin (1992).

**FIGURE 1**
ANALYTICAL MODEL

whose objective is to increase their knowledge base. Therefore, the different development levels of this capacity provide options for access to knowledge, resources, and opportunities (Norman 2002; Cullen 2000; Grandori and Soda 1995). As with absorption capacity, the ability to examine beyond mere connectivity and interaction involves the selection of linkages and the prioritization of relationships that are established with other systems. Ultimately, this ability is what defines how open or closed a system is at different levels of aggregation.

The absorption and connectivity capacities are mutually reinforcing. Systems with higher levels of development of their absorption capacity tend to be more open and sustain a higher density in their relationships with other systems. In turn, these are systems that are better able to reap the benefits arising from interactions generated. At the same time, the density of relationships and the degree of openness of the system, defined by the connectivity capacity, help to develop greater absorption capacity when the system is exposed to significant flows of knowledge that the system must learn to select and use to obtain quasi-rents.

The significance acquired by the absorption and connectivity capacities as well as the existing feedback between them conditions the potential for developing learning processes in firms and hence for generating innovative processes. In the first place, connectivity capacity becomes significant due to the implicit need in the innovative process for relying on knowledge which exceeds that which has been developed internally. This implies that firms should actively seek complementarities which facilitate the development of the innovation process by generating interactions with other agents. (Richardson 1972; Coombs and Metcalfe 2000; Lauren and Salter 2004; Mowery *et al.* 1996; Caloghirou, Kastelli, and Tsakanikas 2004; Teece 1992; Santoro and Gopalakrishnan 2000; Ahuja 2000; Antonelli 2008). Secondly, even when the necessary complementary knowledge exists, firms should rely upon the absorption capacity that allows them to assimilate and exploit external knowledge in order to innovate. In this regard, it is possible to recognize the significance of dimensions such as R&D (Cohen and Levinthal 1989, 1990) and the organizational form (Coriat and Weinstein 2002) in the differential capacity of firms in order to obtain a relatively improved economic and innovative performance (Duysters and Hagedoorn 1996). Despite the existence of a bi-directional relationship, it can be argued that absorption capacity is a necessary condition for the development of connectivity (Erbes, Tacsir, and Yoguel 2008). This result can also be seen from percolation approach (Antonelli 1997; David and Foray 1994), which states that for knowledge to be absorbed by the system, minimum thresholds in both the absorption and connectivity capacities are required. Also, a fundamental property of percolation is that the probability of it occurring is higher in systems with imperfect connectors and high absorption than the opposite. It is necessary to improve absorption capacity so that it is more effective, rather than targeting only increased connectivity.

Both capacities jointly define the minimum thresholds that agents need to meet in order to take advantage of local externalities, present in the multidimensional space, positive feedback, and internal learning processes. Thus innovation and the diffusion of it are not randomly governed events, but require specific behaviour in individual agents and the particular characteristics of the multidimensional space. Finally, innovation depends on agents' capacities developing sufficiently in order to constitute a critical mass of agents with creative reactions playing against the rules. To reach this critical mass of agents playing against the rules requires what in physics is called "phase transition." The idea of phase transition can be useful for understanding the point at which micro interactions trigger qualitative changes in the macro structure.

Therefore, the ideas of critical mass and phase transition constitute a first step in understanding the mechanisms that govern emergence within complex systems. When both absorption and connectivity capacities reach significant levels of development, the system can profit from the local conditions of multidimensional space, including opportunities and risks. In these cases, the system can reach an important stage of development in the interconnected processes of creative destruction, appropriation, and structural change.

From Schumpeter's perspective (1912, 1942), competition between agents is understood as a **process of creative destruction** that generates variety through innovation but also reduces this variety through selection mechanisms. The generation of novelty by the system depends on the creativity in the agents' reactions and local learning in the multidimensional space. Meanwhile, the selection mechanism remains in the institutional sphere. An institutional framework conducive to innovation will select and reward creative behavior. For this to happen, a critical mass of agents playing against the rule is needed. While the selection mechanisms tend to diminish micro-diversity, the creative component of the creative destruction process helps to increase it. In this sense, they are opposing forces and so interdependent that they should have an impact on both competition and development (Metcalfe, Foster, and Ramlogan 2006). Within this framework, competition is understood as a space for generating variety and selecting behavior, rather than as an abstractly constructed intersection between the functions of supply and demand. Therefore, the creative destruction process synthesizes the generation and resolution of economic diversity, which constitutes the main source of growth (Metcalfe *et al.* 2003).

The **appropriation process** (Cohen, Nelson, and Walsh 2000; Antonelli 1997, 2007; Winter 2006; Dosi *et al.* 2006; Pisano 2006; Teece 1986; Erbes *et al.* 2006) refers to a set of mechanisms and skills that allow players to transform knowledge into quasi-rents. This process depends on the way in which technology and knowledge is managed and the dynamics of the creative destruction processes embodied in competition (market share) (Erbes *et al.* 2006). Agents — by differentiating their routines — attempt to appropriate quasi-rents and extraordinary profits derived from the competitive process. With regard to this process, it is necessary to consider those aspects that help to explain why the knowledge embedded in products or services and processes produced by agents might constitute a temporary barrier to entry and become a source of quasi-rents. This issue will depend on the absorption and connectivity capacities related to (i) different sources of knowledge, (ii) learning processes, (iii) the integration of different types of knowledge (Malerba and Orsenigo 2000; Johnson, Lorenz, and Lundvall 2002; Erbes *et al.* 2006), and (iv) the appropriation regime. The appropriation regime sets out the rules and institutions that regulate the boundaries of property rights. This means intellectual property rights and other sources of rents, among them tariffs and non tariff barriers to trade, antitrust legislation, *etc*. In sum, all are factors that explain the current market structure. Nevertheless, these rules can change according to agents' reactions. Regarding appropriation processes, we account for intentional rent-seeking behavior in agents.

Finally, the **process of structural change** describes changes in productive structure that make it more complex, and thus more diversified and better integrated, or simply more developed. In this sense, the process of structural change involves both a specific direction of change and also, as a consequence, development issues (Ocampo 2005; Ross 2005; Palma 2005; Reinert 2007; Cimoli, Porcile, and Rovira 2010). This process takes into account (i) the reallocation of production factors to higher productivity sectors aimed at reducing structural dualism and collecting the gains from increasing returns, (ii) the development of complementarities between agents, (iii) changes in the specialization pattern, oriented towards differentiated products with a higher income elasticity, and (iv) the development of policies to promote the coordination of investment decisions in a context characterized by technological indivisibilities (Cimoli *et al.* 2005). Thus, the process of structural change is not spontaneous. It is the result of a strategic development which implies that players are able to define their behavior in a game in which coordination and information problems are present (Cimoli *et al.* 2005). This concept incorporates both the contributions made by authors such as Prebisch and Hirshman, among others, in the context of development theories from the 1950s, and those generated by new development heterodoxy mentioned above.

These three processes help explain the dynamics of meso and macro structure and the evolution of the economic system as a whole. Thus, in more evolved economic systems economic agents perform complex innovative processes whose benefits are appropriated from different mechanisms, producing a structural change process that modifies the profile of productive specialization. By contrast, in systems with lower levels of complexity, such as those predominating in less developed countries, where adaptive reactions prevail, economic development is conditioned by the system's capacity for appropriating knowledge and performing innovative and structural change processes.

The degree of development of these processes that jointly explain economic development is conditioned by the level reached through absorption and connectivity capacities and the feedback mechanisms between them, which, in turn, depend on the institutional framework. Therefore, the building of capacities determines the degree of development of the processes of appropriation, creative destruction and structural change. Any system requires not only internally produced knowledge but also knowledge derived from relationships with the environment. Therefore, the dynamic of change requires both the existence of linkages with other systems that are functional (connectivity) and skills associated with the identification and implementation of useful knowledge (absorption). Both absorption and connectivity capacities would have strong influences on the agents' creativity.

The relationship between capacities and processes is reciprocal and it is reinforced over time. The feedback dynamic is present not only within capacities and innovation but also within processes of creative destruction, appropriation and structural change. At the same time, these processes also have an impact on the development of capacities. From this perspective, more complex economic systems tend to develop creative capacities that drive changes in the system and in the developing path. In these cases, there is a predominance of agents in which learning is generated from multiple internal and external sources arising from R&D, interactions with universities and technology centers, patents, club goods and production networks, among others. Some of these — especially the latter three — become mechanisms that allow the knowledge to be appropriated and then promote innovation and structural change.

High levels of absorption and connectivity capacities and the presence of feedback between them lead to the development of innovative processes. Innovation, as an emergent property of a complex system, is located in the center of the process of creative destruction. Innovation conditions, and is in turn conditioned by, the features that the process of appropriation assumes. At the same time, the emergence of innovations and transformations in the above processes enable the development of structural change processes. Meanwhile, the processes of appropriation, creative destruction and structural change define the basis on which economic agents must compete, develop their capacities and generate innovations. Therefore, the three processes describe evolution in the institutional framework and then establish the conditions for the appearance, or the blockading, of creative reactions.

As a consequence, the degree of importance of the processes of creative destruction, appropriation, and structural change also affects the learning processes and then the level reached by absorption and connectivity capacities. Higher levels of development arising from the complexity of these processes require and allow the generation of higher capacities in agents that play against the rules. This dynamic strengthens virtuosity between capacities, innovation, processes and economic development. Also, it evidences how capacities determine the development of processes, especially through the accumulation of creative reactions that trigger qualitative changes at an institutional level. At the same time, these feedback dynamics define the possibilities for building up capacities that enable agents' competitiveness to increase.

Nevertheless, this feedback can follow the opposite path: the institutional framework and the features of processes could blockade the development of capacities. When agents' absorption capacities remain low, there is little possibility of establishing linkages that allow agents to learn. Therefore, the feedback that leads to learning and capacities developing processes are weak or inexistent. Therefore, there is little possibility of accumulating creative reaction and reaching the critical mass needed to change institutions. In this picture, capacities and processes reinforce themselves but in a vicious manner that inhibits a phase transition that would lead the system to higher development. In the next sections, we show some empirical evidence for developed, developing, and newly industrialized countries that account for these differential dynamics.

## IV. Capacities and Processes: The Specificities of Economic Development

In the previous sections we defined the complexity of an economic system in relation to the level and evolution of absorption and connectivity capacities, the processes of creative destruction, appropriation and structural change, and the interactions between them. However, these relationships operate differently in developing, newly industrialized, and developed countries. Thus, whereas in more complex economic systems, capacities and processes enhance their development path, in the opposite case, different kinds of blockades limit the feedback between firms' capacities, while the weakness of the processes would constrain the development of capacities.

The different ways in which absorption and connectivity capacities are manifested define different levels of complexity of economic systems. Complexity at the micro level can be accounted for by the diversity and complementarities of agents in terms of capacities, behaviors (creative and adaptive reactions), and the feedback between these. We propose that these differences would result in the existence of countries with uneven developmental potential. The lack of complementarities between capacities would act as a blockade in feedback dynamics. Therefore, the structural heterogeneity (Ocampo 2005) would limit the linkages between firms and thus the multidimensional space, within which firms' interactions would be poorly integrated. Firms' possibilities for building capacities would depend entirely on internal efforts that would in turn be diminished by the scarcity of learning opportunities.

As was suggested in the theoretical framework, the relationship described between absorption and connectivity capacities and their feedback effects is reflected in the importance attained by innovation activities and then by the processes of creative destruction, appropriation, and structural change in countries with different levels of development (see Table 1).

In developed countries and newly industrialized countries, the higher complexity of economic systems is derived from the higher absorption and connectivity capacities and also from the intensity and synergy of the three processes mentioned above. In such a framework, the minimal threshold of competence that the agents need to reach in order to increase connectivity capacity is lower because of (i) the presence of externalities (public goods, spillovers, and infra structure) and (ii) the existence of networks which enable the appropriation processes of club goods generated within them. In spite of the strong differences between development levels of developed and newly industrialized countries, we assume that the dynamic of creative destruction, appropriation, and structural change are similar. What distinguishes these countries for developing countries is that the transition phase has already occurred. In turn, the explanation for this is that the complexity of the multidimensional space reaches the required level of complementary diversity, which allows the interchange of knowledge and learning, thus promoting the development of all three processes.

In developed and newly industrialized countries, the structural change process is favoured by the existence of a specialization pattern with complementarities, high intrasectoral homogeneity, and the presence of firms operating in sectors with Schumpeterian and Keynesian efficiency that entail the existence of high entry barriers, enabling the appropriation of knowledge generated in the form of quasi-rents derived from increasing returns. In these cases, decreasing costs derived from accumulative learning prevail. The existence of externalities and complementarities between agents are key components of systems with highly developed structural change process (Cimoli, Porcile, and Vergara 2005). However, they are also explained by a strong accumulation of knowledge that, in turn, is derived from agents' absorption and connectivity capacities and feedback between the two. As a consequence, the activities that define the specialization profile in these countries can be labeled as 'Schumpeterian' (Reinert 2007), since they are characterized by increasing returns to scale, the dynamic existence of imperfect competition, technical progress and disembodied innovation efforts, and strong synergies between sectors that are possible through complex translation mechanisms between agents (Stokes 1997). The process of creative destruction is aided by the development of market structures arising mainly from a prior accumulation of knowledge, where technology interrelationships are central.

From the perspective of appropriation processes, developed countries stand out because of different appropriation regimes: IPR, secrets, epistemic communities, and high-speed innovation rates. In turn, the resident firms in these countries can reduce the costs of R&D and increase the likelihood of successful innovations by decentralizing activity in many innovative start-ups, which increase diversity and the importance of club goods and commons. One key factor of appropriation processes in developed countries is the whole system's ability to export the institutions that govern the dynamics of this process. Multilateral agreements in the field of property rights (particularly TRIPS, because it is enforced) are an expression of developed economies' capacities to extend the appropriation of technological quasi-rents beyond their own territory.

In addition, in terms of creative-destruction and thus the competitive process, high entry barriers — derived mainly from cognitive abilities — prevail. These kinds of barriers are built and torn down by agents playing against the rules, continuously threatening the established market positions. Agents can take advantage of technological interrelationships and knowledge complementarities resulting from the presence of increasing returns to scale, but the better position is subject to constant peril from the competition or is merely temporary. As a consequence, agents compete amongst themselves in concentrated markets through the introduction innovations. Therefore, the degree of stability of quasi-rents generated by the integration of knowledge is greater than in those systems where agents compete in markets where innovation is not rewarded. Thus, in spite of operating in sectors with strong technical progress and instability, it is possible for them to decode uncertainties.

In developing countries, in contrast, the competition process is based more on prices than on the search for new combinations that are oriented towards the generation of innovations aimed at increasing variety and improving selection. Learning and technological processes have mainly been embodied and they are poorly fuelled by knowledge derived from basic and applied science. This is because the low levels of complementarities among agents and the absence of a critical mass of agents operating in the most innovative sectors. Although in these countries there are innovative firms that actually compete in global markets or firms integrated in global value chain, they are not enough to provoke structural change processes. The existence of agents with high absorption capacity does not imply an increasing in the likely of establishing linkages by itself. It is the critical mass of them what is needed to generate the complementarities. Therefore, the learning and capacity building processes are developed mainly inside firms because of the weakness of linkages of the multidimensional space where they operate. Especially in the cases of linkages with universities and technological centers that would be extremely helpful in developing capacities.

Therefore, the structural change process is limited by the low complementarities of absorption and connectivity capacities and a specialization pattern characterized by the high inter- and intra-sectoral heterogeneity and the Malthusian activities prevail (Reinert 2007). Among the main characteristics of the productive profile should be mentioned (i) the predominance of static comparative advantages, (ii) the outstanding of sectors with technologically low dynamics, with public knowledge, and limited accumulation, and (iii) the major role played by embodied technological progress through the acquisition of capital goods. The latter issue is also evident in the low complexity of networks, although this characteristic does not override the possibility that a few firms in more dynamic industries may exist, grow, and compete globally within the prevalent dynamic specialization profile

**TABLE 1**

SOME INNOVATION STATISTICS IN DEVELOPED AND DEVELOPING COUNTRIES

Latin American countries show considerable differences to developed and Asian newly industrialized countries. In terms of innovation activities, number of patents per million inhabitants is more than 100 times higher in developed countries than in developing countries (on average for the selected countries show in table 2). Regarding R&D expenditure, developed countries show R&D/GDP ratios almost four times higher than in developing countries, where this is highly concentrated in the public sector. Other indicators — such as the number of researchers per million inhabitants and the proportion of enrollment in tertiary education in science and technology over the total 24-year old population — show differences of magnitude that are consistent with the differences in the indicators identified above. In the same direction, the low level of innovative activities is consistent with the poor participation of high-tech sectors in the trade specialization pattern.

Latin American countries could not make the transition from acquired capacities to the dynamic technological capacities required for generating appropriation, creative destruction, and structural change processes. The absence of a critical mass of agents playing against the rules constrains the phase transition that newly industrialized countries could make.

| | 1. Patents granted per million inhabitants | 2. R+D expen-diture/ GDP | 3. % of private R&D over total R&D | 4. Reseachers per million inhabitants | 5. % Tertiary entollment in science and engineering | 6. High tech sector in commercial profile | 7. Overall GDP per capita (2004) | 8. GDP per capita growth (1960-2004) |
|---|---|---|---|---|---|---|---|---|
| France | 55 | 2.12 | 63.4 | 3,353 | 8 | 0.70 | 26,169 | 204 |
| Germany | 119 | 2.52 | 70 | 3,386 | 7 | 0.69 | 25,610 | 115* |
| Italy | 25 | - | - | - | 4 | 0.39 | 23,174 | 226 |
| Japan | 267 | 3.40 | 77 | 5,546 | 8 | 1.16 | 24,660 | 432 |
| United Kingdom | 57 | 1.80 | 62 | 3,033 | 10 | 1.21 | 26,762 | 158 |
| United States | 279 | 2.61 | 70 | 4,651 | 6 | 1.10 | 36,100 | 177 |
| Spain | 7 | - | - | - | 6 | 0.40 | 20,973 | 322 |
| China | 0.5 | 1.42 | 71 | 926 | 1 | 1.69 | 5,333 | 1,099 |
| Korea | 114 | 3.23 | 77 | 4,162 | 9 | 1.79 | 18,421 | 1,093 |
| Taiwan | 258 | - | - | - | 8 | s/d | 20,872 | 1,300 |
| Argentina | 1 | 0.49 | 30.4 | 895 | 2 | 0.08 | 10,945 | 39 |
| Brazil | 0.6 | 0.82 | 40.2 | 461 | 2 | 0.21 | 7,204 | 170 |
| Chile | 0.9 | 0.67 | 46.1 | 833 | 3 | 0.02 | 12,681 | 153 |
| Mexico | 0.7 | 0.50 | 50 | 464 | 2 | 1.22 | 8,168 | 121 |

1. Per million inhabitants at the USPO.
5. As a % over the total 24-year-old population.
6. Reveal comparative advantages. Pharmaceuticals; Electronic data processing and office equipment; Telecommunications equipment; and Integrated circuits and electronic components.

Sources: Millennium indicators. United Nations, UNESCO, United States Patent and Trade Mark Office, Penn table

*In West Germany (1960-1997).

(Erbes *et al.* 2006).

Finally, in these countries, the appropriation process would be characterized by low or null appropriation of quasi-rents because the low absorption and connectivity capacities would inhibit innovation and increase R&D costs, which in turn would affect capacity for catching up. Besides, weak absorptive and mainly powerless connectivity capacities in firms would also condition the significance of creative destruction processes. Low capacities would impact on innovation and hence competition would be based mainly on prices and not an increase in variety and the improvement of selection mechanisms. The structural change processes would be constrained by the low feedback effects of absorption and connectivity capacities. A specialization pattern and an economic structure characterized by the low importance of sectors with high Schumpeterian and Keynesian efficiency (Cimoli, Porcile, and Rovira 2010). This specialization pattern would condition the development of capacities of system components.

As the three processes mutually reinforce each other, the predominant productive and trade specialization pattern (in goods and services) is defined by limited processes of knowledge appropriation, structural change, and creative destruction. The weakness in specialization patterns is also evident in the complexity of networks. Developing countries are therefore characterized by the presence of linkages between agents that assign less importance to the endogenous generation of knowledge with learning sources that are basically internal and idiosyncratic. These patterns are associated with diminishing returns to scale, competition based on prices in highly volatile markets, a demand for unskilled labor, the use of low-quality processes, and mainly embodied technical progress. Developing countries' weakness involves failures in the whole system and not only in firms' behavior. The systemic nature of innovation is less visible in developing countries, resting mainly in individual efforts. Therefore it is easy to find agents performing several functions.[10]

This uneven production specialization is reflected in mechanisms for the appropriation of knowledge that are closer to traditional forms of protection and with limited spillover into the productive structure. Reinert (1995) argues that in such countries there are severe constraints affecting the chances of appropriating quasi-rents derived from knowledge and the classical way of spreading the benefits arising from technological progress. As Cimoli, Porcile, and Rovira (2010) have shown, the nonexistence of convergence and the problems linked to a deficit in

[10] For example, the lack of an appropriate financial system leads to firms self-financing their innovation activities. They may also have to train their employees, substituting educational institutions, among other things. Therefore, attaining a critical mass of agents playing against the rules becomes a hard duty.

Schumpeterian and Keynesian efficiency are explained "mainly because income elasticity of the demand for imports in Latin America has an upward trend which was not matched by a similar increase in exports."

Therefore, because of the low complementarities between agents derived from the prevalent specialization pattern, systemic dimensions are absent and firms' individual efforts are what mainly become relevant. Low levels of both absorption and connectivity capacities would thus limit emergence of innovations within a framework of weakness in the three processes. Therefore, the improvement of these capacities and the upgrading of feedback effects would be necessary conditions for development. A given economy's specialization profile defines a set of dimensions related to the importance of acquiring knowledge, the kind of returns, the generation of competitive advantages, and market forms which are closely linked to capacities and processes (Rosenberg 1982; Reinert 1995, 2007; Rodrik 1999).

## V. Empirical Evidence on Capacities and Feedbacks

In this section we present some empirical evidence based on a group of papers that analyze the relation between capacities, linkages, and innovation.

In Table 2, we synthesized the results of some papers based on innovation surveys carried out mainly within the Oslo Manual framework. The papers were selected according to their objectives by studying the relationship between firms' capacities, linkages, and innovation. Assuming that the capacities can be read as absorption capacity and the linkages are a proxy variable of connectivity capacity,[11] we have focused on the causality these papers propose so as to discern whether or not they put forward the existence of the feedback that we postulate theoretically in our model. From this perspective, the literature can be categorized into three different cases: (i) where absorption capacity mainly explains connectivity, (ii) where there is a bidirectional relationship between capacities and linkages, and (iii) where both capacities explain innovation. We have organized the table in order to present the evidence for developed, developing, and newly industrialized countries.

In terms of absorption and connectivity capacities, the studies that

[11] Although in most of the papers quoted firms' linkages refer to R&D cooperation, for the purpose of this paper we assimilate those linkages to connectivity capacities.

**TABLE 2**

THE RELATIONSHIP BETWEEN COMPETENCIES AND COOPERATION: THE RECENT INTERNATIONAL LITERATURE

| | Papers | Objectives | Methodology | Capacities |
|---|---|---|---|---|
| | | **Developed countries** | | |
| AC → CC | -Kleinknecht and Reijnen (1992) (Netherlands)<br>-Fritsch and Lukas (2001)<br>-Tether (2002) (UK)<br>-Veugelers and Cassiman (2005) (Belgium)<br>-Miotti and Sachwald (Several counties) (2003) | To analyze the determinants of R+D cooperation and the patterns, diversity and barriers to this. | Multivariate analysis and logistic and probit regressions and Poisson Hurdel models. | AC: occasional, continuous, and intensive R+D activities. R+D intensity and own R+D department.<br>CC: formal R&D agreement with universities and with other firms (vertical and horizontal). |
| AC ↔ CC | -Veugelers (1997) (Belgium)<br>-Becker and Dietz (2004) (Germany)<br>-Vega-Jurado *et al.* (2008) (Spain)<br>-D'Este and Neely (2008) (UK) | To study the two-way relationship between external R&D activities and internal R&D expenditures and their effect on innovation. Interaction of university researchers with industrial partners. | Structural equation model, simultaneous equation system, and multivariate logistic regression. | AC: own R+D infrastructure and personnel and R+D intensity.<br>CC: presence of I+D agreements, number of partners, consideration of different types of agents. Agreement between university researches and industrial partners. |
| AC and CC → I | -Belderbos, Carree, and Lokshin (2004) (Netherlands)<br>-Nieto and Santamaría (2007) (Spain)<br>-Caloghirou, Kastelli, and Tsakanikas (2004) (different European countries)<br>-Miotti and Sachwald (2003) (different European countries)<br>-Vega-Jurado *et al.* (2008) (Spain) | To analyze the effects of cooperation networks on existing internal capabilities on the level of innovativeness. | Bi-variated probit analysis and ordinary least square. | AC: innovation intensity and personal qualification.<br>CC: cooperation agreement on R+D (vertical and horizontal). Cooperation with universities. |

(Table 2 Continued)

| | Papers | Objectives | Methodology | Capacities |
|---|---|---|---|---|
| | | **Newly industrialized** | | |
| AC → CC<br>AC → I<br>AC and CC → I | Eom and Lee (2008) (Korea)<br>Tsai and Wang (2009) (Taiwan) | To analyze the effects of internal R&D and the acquisition of external knowledge (outsourcing and cooperation) on innovation. | Technological survey and other sources. Absorption capacity (R&D intensity). | AC: internal R&D (R&D/total employees with tertiary education, R&D intensity).<br>CC: horizontal and vertical cooperation. Cooperation with universities and technological centers. |
| | | **Developing countries** | | |
| AC → CC | Bianchi, Gras, and Sutz (2008) (Uruguay)<br>Garrido Noguera and Padilla-Pérez (2008) (Mexico)<br>Benavente and Contreras (2008) (Chile)<br>Kupfer and Avellar (2008) (Brasil)<br>Arza and López (2008) (Argentina) | To analyze the determinants of firms connectivity. | Probit and logit models | AC: R+D intensity, highly skilled employees.<br>CC: cooperation agreements with firms (vertical and horizontal). Cooperation with universities. |
| AC ↔ CC<br>AC and CC → I | Erbes, Robert, and Yoguel (Forthcoming 2010) (Argentina) | Analyze feedback effects between absorption and connectivity capacities and their impact on innovation. | Probit and bivariated probit models. | AC: quality management, labor organization, and R+D intensity.<br>CC: quality of linkages with firms, intermediate institutions and universities. |

Note: AC, absorption capacity; CC, connectivity capacity; I, innovation

analyze the arrow of causality from absorption capacity to linkages stress that in order to take advantage of the cooperation process firms need internal technological expertise. In one of the first studies about these issues utilizing a representative sample of industry and service firms, Kleinknecht and Reijnen (1992) point out that the role of formal R&D department is a key factor in explaining cooperation with foreign firms and R&D institutes. They have emphasized that R&D departments not only produce internal knowledge but also enhance firms' capabilities for using external sources of knowledge. Many authors have stressed that firms with higher innovation capacities are more likely to cooperate with universities and technological centers than with suppliers and customers (Veugelers and Cassiman 2005; Miotti and Sachwald 2003). Tether (2002) analyzes cooperation for innovations between firms and their suppliers and customers. He points out that the importance of cooperative activity for the development of innovations depends on both the types of firms and on what is meant by innovation. The author stresses that 46% of the firms identified as innovators claimed to have some form of cooperative arrangement for innovation and over a fifth part of them had cooperative arrangements with suppliers and customers. In relation to absorption capacity, he finds that those firms with high innovation patterns[12] were more likely to have cooperative arrangements for innovation with external partners. In addition, the proportion of firms with cooperative arrangements did not tend to increase according to the ratio of R&D personnel to total employment. These issues mean that a minimum threshold for absorption capacity is a necessary condition for engaging in a cooperation strategy.

Other authors reflect a bi-directionality in the relationship between firms' capacities (Veugelers 1997; Becker and Dietz 2004; Vega-Jurado *et al.* 2008; D'Este and Neely 2008). For example, D'Este and Neely showed that university researchers interact with industry for a diverse set of reasons. In terms of the determinants of university-industry linkages, these authors use a long list of interactions between university researchers and industrial partners and find that the persistence of involvement in R&D activities is more important than the extents to which firms engage in R&D. Therefore, the firm's absorption capacity is influenced by the cumulative nature of engagement in R&D. They also point out that firm size and geographical proximity are important factors in the appropriation of interaction benefits. Therefore, in such developed countries the cooperation between firms and universities and technological centers depend on absorption capacities — estimated by means of R&D involvement — and have a strong influence on the innovation process.

In the same group, Vega-Jurado *et al.* (2008) discuss how the level of cooperation with scientific agents depends on firms' technological, human resource, and organizational competencies, which in turn are

[12] These are firms that fulfill the following conditions: undertaking R&D on a continuous basis and with great intensity, introducing at least one innovation not only new to the firm, and trying to overcome problems with customers that impose difficulties on its innovation processes and problems derived from the lack of financing of innovation.

assimilated to Cohen and Levinthal's notion of absorption capacity. They suggest that in-house R&D brings about benefits not only by generating new knowledge but also by assimilating and exploiting knowledge that is external to the firm, thereby later increasing its absorption capacity. In order to explain the degree of innovations of firms, they use industrial and non-industrial technological opportunities (vertical and horizontal cooperation and cooperation with universities and technological centers, respectively) and appropriation conditions (legal and strategic) as other independent variables. They stresses that internal R&D explains the development of new products in firms more than cooperation with scientific agents, which means that in Spain these firms do not use cooperation with universities and technological centers as a means for improving their competencies. On the contrary, this kind of cooperation is important in those firms with low competences. They also show how vertical cooperation is a key factor for the development of new products in traditional firms but not in science-based firms.[13] In relation with this issue, Fritsch and Lukas (2001) and Becker and Dietz (2004)[14] show that industry cooperation oriented to R&D projects is complementary to internal resources in the innovation process. Therefore, it enhances the intensity of in-house R&D and the probability of developing new products.[15] Besides, the intensity of in-house R&D also stimulates the probability and the number of joint R&D activities with other firms and institutions significantly, which means the presence of feedback effect.

The third kind of studies (Belderbos, Carree, and Lokshin 2004; Nieto and Santamaría 2007; Caloghirou, Kastelli, and Tsakanikas 2004; Miotti and Sachwald 2003; among others) show that both the absorption and connectivity capacities have a strong influence on the innovation process. For example, Belderbos, Carree, and Lokshin (2004) show that industry-university cooperation is positively associated to the emergence of radical innovation. Using a CIS survey, they analyzed the impact of cooperation of firms with different partners for innovation on

[13] The case of Spain is interesting as an example of a country that, in spite of a significant convergence process, has some indicators that are even lower than the average for developed countries, but substantially higher than developing ones.

[14] According to these authors, internal capacities affect the use of external resources and help firms in developing connectivity capacities.

[15] About 37% of 2,048 firms have cooperated with other agents to develop new products jointly.

labor productivity and for innovation sales productivity growth. They found that while supplier and competitor cooperation impact on labor productivity growth, cooperation with universities, technological centers, and competitors impacts on the rate of growth in sales per employee in innovative products new to the markets. In a context in which relationships with suppliers and customers are more frequent, the authors found that R&D intensity had a positive impact on cooperation, both vertical (suppliers and customers) and horizontal (competitors) networks.[16]

In sum, in developed countries firms' connectivity is oriented mainly to R&D. As we will show in the next section, in spite of this causality, there is a great difference between these connectivity capacities and those of firms belonging to developing countries.

Regarding developing countries, several empirical studies carried out in Latin America reveal that, during periods of growth and economic stagnation, technological and organizational competencies are weak with a preponderance of embodied innovation efforts and low levels of disembodied efforts in the innovation process (Kupfer and Avellar 2008; Benavente and Contreras 2008; Garrido Noguera and Padilla-Pérez 2008; Bianchi, Gras, and Sutz 2008; Erbes, Robert, and Yoguel Forthcoming 2010; Roitter *et al.* 2007; Albornoz and Yoguel 2004; among others). The firms' connectivity, both between each other and with institutions of the national innovation system, is reduced. At the same time, economic agents are embedded in productive networks where absorption capacity is low. These studies also show that there is some sort of non-virtuous association between competences and linkages. In such a context, reduced levels prevail in both dimensions.

For the case of Argentinean production networks, Erbes, Robert, and Yoguel (Forthcoming 2010) test the relationship and feedback[17] between absorption capacity[18] and the quality of linkages that firms establish with different types of agents.[19] These effects were found in

[16] In terms of cooperation determinants, they focus mainly on R&D intensity and incoming spillovers.

[17] In order to test feedback, the paper proposes a comparison of the results of Probit regressions with Bioprobit (a model controlled by endogeneity).

[18] In this paper the absorption capacity index is estimated as the average of the following four variables: (i) quality management, (ii) training activities, (iii) work organization, and (iv) the presence and type (formal or informal) of the R&D team.

[19] In the building of connectivity capacity, this paper considered three different types of partners related to the quality of the firms' linkages: (i) other firms, such as customers, suppliers, and competitors, (ii) intermediate institu-

linkages with intermediate institutions and universities. In contrast, the weakness of production networks came from the absence of a relationship between absorption capacities and quality linkages between firms and the absence of feedback between these dimensions. According to the authors, there is a need for minimum thresholds for absorption capacities if quality linkages with intermediate institutions, universities, and technological centers are to be accessed. This implies not only the relevance of minimum thresholds but also the need for firms' capacities to learn from these linkages. In explaining the innovation results by means of absorption and connectivity capacities, they show that while the level of agents' absorption capacities is central in explaining the results of innovation, the quality of linkages is not significant. The absorption capacity determines the system's potential for accessing the knowledge disseminated in networks and environments which they belong to. Nevertheless, whether or not firms with high capacities exist in the neighborhood also affects the quality of linkages, which is explained by the local search within the multidimensional space. Even more, there are other factors at macro levels that affect both capacities, such as specialization patterns, firms' positions in the global value chain, and more generally, the weak dynamics of the appropriation, creative destruction, and structural change processes. Both capacities define the minimum thresholds the agents need in order to appropriate the externalities generated in the environment (when these exist) and the results of the processes and learning taking place internally. Thus, dissemination of knowledge does not occur randomly between the components of a system, but a wide variety of capacities are associated with the absorption of knowledge and connections between other agents.

In a similar direction, other studies based on Latin American technological surveys and other sources show that the learning and technological change are mainly of an embodied nature. These processes are poorly fueled by knowledge derived from basic and applied science

tions, such as chambers of commerce and consultants, and (iii) academic and research institutions, such as universities and science and technology centers. In order to evaluate the quality of the relationships, the paper took into account the quantity of objectives involved in the linkage, considering a higher number of objectives as a preferred situation. The goals of linkages considered in the survey were those relating to: commerce, quality assurance, human resources training, designing and development activities, finance for innovation, sharing of infrastructure, reducing costs and risks of innovation, organizational changes, and environment improvements.

and from firms' linkages with the environment, especially with universities and technological centers (in Argentina, Lugones and Suárez 2006; Roitter *et al.* 2007; Albornoz, Milesi, and Yoguel 2005; Borello, Morhorlang, and Silva 2010 Forthcoming; Marin and Bell 2006; Albornoz and Yoguel 2004; in Brazil, Kupfer and Avellar 2008; in Chile, Benavente and Contreras 2008; in Mexico, Garrido Noguera and Padilla-Pérez 2008; in Uruguay, Bianchi, Gras, and Sutz 2008; and in Latin America in general, Cimoli, Primi, and Rovira 2008).[20]

In the case of Uruguay, the ratio of firms cooperating for R&D with suppliers, customers, and other firms was only 3.4% but increased to 60% in firms with highly skilled employees. In addition, absorption capacity is the most important factor in explaining collaborative cooperation with research institutions. The authors also stress the limitations of technological surveys to go beyond traditional innovation indicators. This important issue is manifested in the fact that more than a half the firms declaring that they perform R&D do not have a single employee with competencies originating in science or engineering education (Bianchi, Gras, and Sutz 2008). The study of Mexico (Garrido Noguera and Padilla-Pérez 2008) stresses that cooperation between firms and with universities and research centers were almost inexistent. They support the idea that the intensity of R&D, and thus of absorption capacities, is expected to increase the likelihood of innovation. Therefore, the development of absorption capacity is a necessary condition for cooperation with the aim of innovation to take place. In this context, the cooperation of innovative firms with other firms (11.1%) is higher than their cooperation with research institutes and universities (1.1%). The study suggests that policies to improve cooperation should unite with policies oriented towards fostering R&D activities. In the case of Brazil, Kupfer and Avellar (2008) show that only 12% of innovative firms had cooperated with other firms and 8% with universities and technological centers. There are also strong sectoral and size specificities. In addition, by studying the marginal effects of the variables that explain the cooperation strategies of innovative firms, the authors show the importance not only of size but also of the significance of capacities (skills, R&D, differentiation, and S&T infrastructure) in explaining cooperation with S&T institutions and other firms. Finally, Benavente

[20] The papers of Kupfer and Avellar; Benavente and Contreras; Garrido Noguera and Padilla-Pérez; Bianchi, Gras, and Sutz; Cimoli, Primi, and Rovira were written as part of an IDRC-CEPAL project.

and Contreras (2008) show that in Chile "peer behavior seems to be very important to deciding to outsource technical activities." These authors pointed out that "confidences, trust, and respect for property rights are different expressions of these transactional costs and are highly relevant in explaining the probability that a firm may sign cooperation agreements as well as the amount of these technical contracts."

Finally, in these countries, there is a lack of agents playing against the rules — in the sense mentioned above — and therefore the three processes are very weak. These issues limit the feedback from processes to capacities and act as a blockade to the development path.

In the case of Korea, Eom and Lee (2008) show the role of cooperation of firms with universities and Government Research Institutes (GRI). The GRI, oriented to sharing risks, have been more important than cooperation with universities to foster the innovation processes. Besides, they stress that the impact of firms' linkages with GRI is manifested mainly through patents and more in innovation processes than in products. In Korea, 40% of innovative firms cooperate with other agents, which is a much higher proportion than in the Latin American countries discussed above. In the econometric models the authors show that cooperation with universities and GRI do not depend on size and on absorption capacity but on government policy. They also show that the importance of patents is more related to cooperation with universities. Finally, cooperation with neither GRI nor universities impacts on the innovation process, the direct support program and cost-push and demand pull factors being more relevant.

In the case of low- and medium-technology firms in Taiwan, Tsai and Wang (2009) show that firms' internal R&D and therefore minimal threshold of absorption capacity are key factors in explaining access, use, and the impact of vertical, horizontal, and scientific cooperation on firms' performance. In addition, they stress that in spite of the great development of market procurement in these firms (R&D outsourcing and inward technology licensing), these sources are less relevant to innovation performance than in-house R&D. The authors also remark that in explaining innovation performance, there are no complementarities between internal R&D and external knowledge acquisition.

This evidence reveals differences between Korea and Taiwan, on the one hand, and Latin American countries, on the other. Cimoli, Dosi, and Stiglitz (2008) stress that only the former have made the transition from production capacities to the technological capacity required for generating technical change. This perspective is also shared by other authors as Chang (2002, 2009) and Lundvall, Intarakumnerd, and Vang-Lauridsen (2006). On the one hand, Chang demonstrates that the successful economic performance of some East Asian countries as Korea is based on the change of specialization pattern towards knowledge intensive sectors, support to the infant industry, and key role of industrial and technological policy allowing them to leave a Ricardian or Herscher-Ohlin specialization pattern. He also shows how the causality goes from development to change in culture. On the other hand, Lundvall, Intarakumnerd, and Vang-Lauridsen stresses on the presence and development of skill people and technological capabilities, certain degree of control over the process of internationalization, coherence in the society and acceptance of certain rules promoting the public space. From this perspective, these countries have moved away for low wage competition and have build specialization capabilities at the regional level.

## VI. Conclusions

In the previous sections we have stressed the fact that, in order to generate a development path, developing countries face the challenge of building absorption and connectivity capacities and of increasing the importance of quasi-rents appropriation, creative destruction and structural change processes. For this to happen, positive feedback effects between capacities, and between processes and capacities, should be generated.[21] As a result, innovation would be an emergent property of the system. We have also stressed that when a predominance of decreasing returns are the main characteristics of the specialization pattern, processes and capacities are very weak and hence it is not easy for a group of agents — both public and private — playing against the rules to appear and promote institutional change. The possibility of creating a development path and high complexity levels are therefore very low. In consequence, instead of structural change there is struc-

[21] The creation of pathways for positive feedback are stressed by Aghion, David, and Forey (2008). For these authors, "positive feedbacks are the source of dynamic instabilities that give rise, in turn, to the existence in the systems of multiple attractors or equilibrium configurations" In terms of amplifying the positive feedback effects of key policy interventions, they suggest using the structure of micro-level incentives created by complementarities in technical systems and organizational mechanisms (p. 14).

tural heterogeneity, a low level of complementarity, and high productivity gaps between sectors. In sum, the weaknesses of the specialization pattern are associated with the low probability of economic development. So, the challenge for developing countries is to increase the complexity of the specialization pattern in sectors where agents are price-formers rather than price-takers, and where the development of absorption and connectivity capacities become a key factor in the competition process. As developed countries have absolute advantages in the most technologically dynamic sectors and in most dynamic stages of production networks, the development path needs to catch up. For this to happen, and to reduce the technological gap between developing and developed countries, industrial and technological policies oriented towards generating dynamic market failures in developing countries are key factors. This is because free market conditions will consolidate dominant positions in the world market and a specialization pattern in developing countries intensive in the abundant factors.

The analytical framework based on complex systems theory — and applied to innovation economics — also provides an appropriate framework for the discussion of industrial policies from a systemic perspective. Following Cimoli, Dosi, and Stiglitz (2008), industrial policy can be defined as a process of institutional engineering that shapes the behavior of agents and comprises not only support to infant industries, but also trade policies, science and technology, public procurement, and FDI and IPR policies.[22] Under this approach, industrial policies should be able to define the steering of the processes of appropriation, creative destruction, and structural change and foster absorption and connectivity capacities. Those policies ought to promote the emergence of a critical mass of agents playing against the rules, whether they belong to the public sector, are incumbents or new agents.

In this sense, industrial and technological policies should take into account some of the issues discussed in this paper if they are to meet the objective of increasing the levels of capacities and processes, and hence create potential for development. In particular, assuming that the economic system is a complex system, a set of specific problems needs to be introduced. For example, the outcomes of policy intervention could go beyond policy agency control and policy makers' decisions

[22] As these authors say, institutional engineering implies congruence between capacity development and the institutions that govern the information distribution and the structure of incentives in the economy.

could therefore trigger destabilizing positive feedback dynamics if they do not consider the interrelationship that governs the dynamics of capacities, processes, and feedbacks.

It must be also taken into account that policy makers should learn from past interventions, because policy should be considered as an experimental and dynamic process (Metcalfe *et al.* 2003). This experimentation could be carry out in a virtual environment using simulation models in order to learn about qualitative changes in complex dynamics. Nevertheless, these simulations do not provide enough information about the critical determinants in complex systems that involve human behavior (Aghion, David, and Forey 2008). The experimental character of policy is therefore crucial.

In order to develop absorption capacities and to spread knowledge and information within and between firms and production networks, incentives must be created for the development of endogenous competencies.[23] One type of policy acting on the improvement of absorption capacities is suggested in Spain by Vega-Jurado *et al.* (2008). According to them, these policies should strengthen firms' technological competences, which are the main determinants both of innovation and of cooperation with scientific agencies. Cimoli, Dosi, and Stiglitz (2008) pointed out that absorption capacities condition the likelihood of generating emulation processes, which also depend on the appropriation regime and the specialization pattern. They also stressed that the accumulation of capacities and knowledge involves improvements in workers' and professionals' skills but also in organization routines. Educational efforts are crucial but from an organizational perspective, policies should be oriented towards resolving persistent inabilities to find opportunities.

The development of connectivity capacities requires linkages between firms and institutions from the perspective of a non-linear model (Stokes 1997). On the one hand, policies should be oriented towards better positioning local agents in the hierarchy of the global value chain or networks that they belong to. This implies developing a public policy that takes private nucleus-supplier-client relationships into ac-

[23] The development of these competences should by centered around (i) the systemic training of workers and employees, (ii) the development of continuous improvement and quality assurance processes (Formento, Braidot, and Pittaluga 2007), (iii) post-Taylorist forms of work organization (Pujol, Delfini, and Roitter 2010 Forthcoming) and a significant increase in the role of design as a source of quasi-rents.

count. In this sense, enhancing the generation, circulation, and appropriation of knowledge in order to create dynamic competitive advantages is necessary. On the other hand, the policy should consider the development of firm-university linkages within a framework that goes beyond individual supply and demand conceptions and human resource training. This requires the prioritization of basic research oriented towards vacancy areas and the development of translation functions between agents in terms of languages and the discovery of new contexts. All of these actions should be complemented with the infrastructure development of free-access ICT.

In term of processes, deep institutional changes are needed to increase their levels of complexity and to overcome the blockades in the feedback dynamics. Policy objectives should then be to create the conditions and rules that promote the actions of new or incumbent agents playing against the rules. The direction of knowledge and capacities accumulation in order to generate catching-up processes is not the same as that which is present in the current institutional framework. Therefore, industrial policy in a broad sense ought to have the political ability to drive development rents towards actors and agents capable of generating structural change, destructive creation, and appropriation processes.

In order to improve the virtuosity of appropriation processes, the extent to which public goods are present becomes a key issue, since these constitute a basic input for the development of club goods. For this purpose, it is necessary to improve the education system — especially at primary and secondary levels — to avoid the increase of perverse selection mechanisms, and to create equal opportunities in access to tertiary education. What is more, from the perspective of the determinants of quasi-rents appropriation, policies should focus on a significant increase in accumulation knowledge embodied into the production of goods and services. This entails not only harnessing the company's external sources by improving the inter-phases between the firms and the scientific system but also improving internal sources by consolidating agents' basic competencies and the circulation of information and knowledge within the companies and networks they belong to. This implies the development of institutions that both allow appropriation as a system of intellectual property rights and reinforce alternative and endogenous forms of protection, such as high innovation rates and high cognitive capabilities, enabling agents to make up epistemic communities in which club goods circulate.

On the other hand, actions oriented towards improving the processes of creative destruction should be related to increasing the weight of knowledge-intensive actors through the selection of sectors with potential for development — which increasingly incorporate knowledge — and the promotion of new ones. This requires the application of a vertical policy that would raise the level of knowledge in the present productive structure and modify the specialization profile by taking advantage of the steep learning curves associated with key sectors in the new paradigm. Therefore, the vertical policy must be centered on (i) the promotion of learning processes and competition between agents; (ii) the generation of dynamic market failures and processes of technological accumulation with positive externalities, and (iii) the incentive to innovate and create institutional mechanisms that reduce the failures selection and increase the emergence of agents playing against the rules. In turn, all these policies entail the development of incentives to build complex routines in order to increase knowledge protection and allow greater appropriation of quasi-rents coming from barriers and imperfect competition and from the development of monopolistic rents from emulation patterns (catching-up).

In turn, the promotion of the structural change process would require (i) important efforts to promote infant industry learning (Cimoli, Dosi, and Stiglitz 2008) and to catch up, especially in the sectors linked to the techno-organizational paradigm, (ii) to induce a complex profile of specialization in goods and services, increasing the weight of sectors with high levels of productivity, and (iii) to develop knowledge and productive complementarities between agents. In both cases the creation and consolidation of organizational structures that connect the market and firms — such as different kinds of networks — are key. These organizational structures have an important role in promoting complementarities between both agents and institutions operating as translators and/or bridges institutions (Casalet 2005). Moreover, to make these processes more dynamic, the specialization pattern must be discussed, promoting the development of those activities with increasing returns and enabling productivity increases that could spill over into other activities. In turn, these activities favour a more virtuous export specialization pattern in terms of knowledge embodied in products and services.

The ultimate goal of this kind of policy is to move forward on the path of development. Therefore, because of the synergy generated by the processes and capacities associated with complex systems, the policy objectives described above are strongly linked. The improvement of knowledge management by integrating tacit and codified knowledge should have a direct impact not only on the level of agents' absorption capacities but also on their connectivity capacities. In other words, policy tools acting from both the demand and supply perspectives are necessary. However, this also requires significant changes in the organization of firms into more complex structures in order to simultaneously include projects in competition in a context of top-down and bottom-up relationships. Changes in these directions will enable firms to diversify learning sources by complementing the inclusion of embodied technical progress with disembodied progress, such as the development of formal and informal R&D activities, design, knowledge integration from different areas of the organization using specific software, *etc*. Therefore, increasing complexity in firms' knowledge management should produce a greater weight of patents, a greater importance of codifiable but un-coded knowledge (displaced code books such as those cited by Cowan *et al.* 2000), and a greater speed of innovation than that rival firms. Finally, this set of policies associated with each of the processes analyzed will also tend to generate a significant increase in agents' absorptive and connectivity capacities.

The design of these policies needs to move along a path in which there is a tension between public and club goods. On the one hand, knowledge is increasingly becoming a restricted access club good derived from the development level of the absorption and connectivity capacities discussed in the previous sections. On the other hand, in the present knowledge-intensive techno-productive paradigm, the chances of development are associated with a wide dissemination of knowledge in the form of public goods as well as club goods because of the growing importance of production networks and linkages between agents. This issue does not imply an inability to capture and generate quasi-rents but does entail more openness in the competitive process (greater variety and better selection) where barriers to entry are generated from agents' different competences on the one hand, and appropriation, creative destruction processes, and structural change, on the other.

Finally, as Reinert (1995, 2007) has proposed, from a neo-Schumpeterian approach, it is possible to identify uneven development in developing countries when (a) the appropriation process is weak (classical diffusion), (b) the country specialization is focused on economic activities with low innovation rates and, therefore, (c) the destruction component of the creative destruction process predominates over the creative one. In these cases it is easy to specialize in being poor in the international division of labor. If the specialization pattern is focused on products with exogenous innovation processes, the discussion about appropriation of quasi-rents does not make any sense. As consequence, these types of countries' growth paths will depend strongly on the international prices of the main products in the specialization pattern and not on their absorption and connectivity capacities which, in turn, condition agents' possibilities of innovating and appropriating quasi-rents related to knowledge. As a consequence, policy prescriptions oriented towards a specialization pattern based on static comparative advantages are a luxury that only developed countries can afford (Cimoli, Dosi, and Stiglitz 2008).

From this perspective, appropriation, creative destruction, and structural change processes, on the one hand, and absorption and connectivity capacities, on the other, become key points in the development process and structural change path. Developing capacities and processes from a complex systems approach applied to the economy means taking advantage of windows of opportunity by choosing the right technology and knowledge management, and operating in oligopolic markets in order to participate in virtuous global production networks. These windows of opportunity are a moving target (Perez 2004; Reinert 2007), and they depend on the processes, capacities, and properties discussed above.

The complex systems approach presented in this paper can explain why divergence and heterogeneity are the main trends in the world economy. It is possible to foresee these patterns when there are complementarities and feedbacks in a system but the other mechanisms are absent or very weak. In these cases, the initial differences between developed and developing countries will be amplified and the catching-up process will not be possible.

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