The complex dynamics of economic development

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Introduction

In recent decades, the complexity approach has been adopted to explain some characteristics of evolutionary micro-dynamics by different heterodox authors (Dosi, Silverberg, and Orsenigo, 1988; Mirowsky, 1989; Dosi, 1991; Dosi and Kaniovski, 1994; Dosi and Nelson, 1994; Foster, 1993 and 2005; Witt, 1997; Antonelli, 2007). According to them, taking complex systems as a framework allows an understanding of the morphology and dynamics of innovation systems characterized by (i) micro-heterogeneity in terms of competencies and linkages, (ii) temporal irreversibility, as a result of a dynamic driven by a non-ergodic path dependence, (iii) disequilibrium, non-linear interactions and feedbacks and (iv) the presence of institutional rules.

Nevertheless, some authors of the old development school and post-Keynesian economics have already dealt with some of these features, especially those related to macro-complexity. Kaldor (1966), Myrdal (1957), Prebisch (1959) and Hirschman (1958), among others, had already considered the effects of the economic structure on development, temporal and structural irreversibility, and the existence of divergent dynamics between countries and regions, reinforced by feedback effects between product growth and productivity (Kaldor-Verdoorn Law), demonstrating that disequilibrium and non-linear dynamics have a long tradition in the heterodox streams of economic thought.

New emerging literature on development (Ocampo, 2005; Amsdem, 2004; Reinert 2007; Cimoli and Porcile, 2009, among others) showed the necessity for the integration of the microeconomic-complexity described by neo-Schumpeterian and evolutionary theory of innovation and the macro-complexity reflected in Latin American structuralism. For example, Cimoli and Porcile (2009) insist on the importance of studying the interaction between the evolution of productivity, aggregate income, and employment levels in the economy, by one hand and technical change, learning dynamics, and structural change that could promote or blockade the development path, by the other.

In spite the macro- and micro-complexity identify by these streams, during the ‘90s Latin America experienced the implementation of a model that stands out because of its utter simplicity: the Washington Consensus policies of liberalization and deregulation. The main assumptions of these policies were that trade and financial openness in the region would lead to increased competition and therefore successful performances in local and global markets, under the assumptions of perfect information, the predominance of decreasing returns and technology as a public good. Far from encouraging the development of skills in local firms, this openness brought about the

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destruction of the capacities built up during industrialization based on import substitution. The openness has also pushed for the internationalization of regional economies based on static advantages such as natural resources, industrial commodities, and low-wage labor-intensive sectors, which provoke an increasing in the structural dualism.

The region's poor growth under the Washington Consensus policies has revived the development debate. The overall objectives of this chapter are to present the major trends in this debate and to contribute to the theoretical integration of the micro-diversity of evolutionary theory of innovation with the macro-complexity of old development school under a general framework of complex systems in order to analyze some features of the development problem.

As was pointed out by Antonelli in the introduction of this book, "an innovation economics approach to complexity thinking makes it possible to go beyond the limitations of both general equilibrium economics and evolutionary analysis into a system dynamics approach." This is the case since 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 considering innovation as an endogenous property (Antonelli, 2009). Hence, innovation is not only the result of the intentional action of each individual agent, but is also an endogenous product of system dynamics. In this sense, innovation constitutes an emergent property of the system because it is not entirely determined on the micro or macro levels, but is –instead- a result of continuous interaction between these two.

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 and connectivity capacities, which define the architecture of connections. The interactions between the system's components trigger changes in its capacities. Thus, firms' capacities reinforce themselves through feedback mechanisms, allowing capacities and connections to co-evolve over time. Together, capacities and feedback mechanisms induce firms to undertake different innovation efforts. However, the results of these efforts not depend exclusively on the firms' behavior but also on the macro and meso dynamics. We propose that these dynamics can be characterized by the processes of creative destruction, appropriation and structural change, which in turn, will take specific features in developed and developing countries and will define whether the institutional framework is conducive or adverse to innovation (North, 1990, Rivera Rios et al 2009). As a consequence of the interaction between these processes and the firms' capacities, innovation endogenously emerges. We assume that the levels of absorption and connectivity capacities, the feedback mechanisms between them, and the characteristics of the meso and macro dynamics could help to differentiate developing and developed countries.

The main questions of this chapter 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, 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 institutional framework adverse to innovation that limits creative reactions of agents, the generation of positive feedbacks between capacities and knowledge spillovers?

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 the adaptive reactions stand out. 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. The 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 implies intentional creative reactions of agents that threaten the technological, organizational, and institutional conditions on which quasi-rents are generated and distributed. 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 mentioned processes. Hence, our characterization of developing countries is that where there are indeed agents that play against the rules but they are not enough of them to change the specialization pattern and the main characteristics of meso and macro dynamics. According to North and Hoff and Stiglitz, endogenous or exogenous shocks are needed to bring about changes in the institutional framework. We assume that the success of these shocks in changing the institutional framework will depend on the existence of a critical mass of agents playing against the rules that enables a phase transition to trigger relevant changes at macro level.

The rest of the chapter is structured as follows. In the second section we briefly introduce some questions related to the development debate in Latin America. The third section introduces the complex systems approach and its specificity to the study of innovation economics and development issues. The fourth section presents an analytical model that explains the dynamics of economic development within a framework that combines Schumpeterian and evolutionary innovation approaches, new development streams, and complex systems theory. In the fifth part, we will apply the analytical framework in order to discuss the specificities of development dynamics. Finally, the closing section deals with the topic of how the complex systems approach obliges development policies to be rethought.

2. The development debate: the complexity of structural change

For the well-known development economics school of the ‘50s (Hirschman, 1958; Rosestein-Rodan ,1943; Prebisch, 1959, Singer, 1950; Nurkse, 1952; Myrdal, 1957), the fact that the production structure in peripheral economies is a key limiting factor to development is explained by trade and production specialization patterns based on commodities and products intensive in natural resources, deteriorating trade terms, and deficits on the balance of payments.

Some issues related to complexity and feedback effects from a macro perspective can be found in these authors. For example, Myrdal analyzed how the divergent paths in

developed and developing countries are accumulative, because cumulative causation between immigration, wages and employment. He stressed that, the investment rate depends positively on the previous income level which is reinforced through several mechanisms like increasing returns, increasing productivity and immigration. According to Myrdal (1957, p. 162), economy growth in receiving areas but decreases in sending areas, bringing about further disparities in wages and employment, leading to additional migration, and ultimately creating a "circular and cumulative causation of migration".

In the '60s, Kaldor (1966) developed his theory of cumulative causation and its effects on dynamic increasing returns, competitiveness, growth, and productivity. The Kaldor-Verdoorn law synthesizes some non-linear dynamics and feedback effects derived from the relationship between productivity and product growth. According to McCombie (1983) the Verdoorn Law forms the core of the cumulative causation models. "The output growth of domestic prices is a function of the growth of wages and the growth of productivity, and the growth of productivity is a function of the growth of output. Hence an increase in output growth will lead to a virtuous circle, with the resulting increase in productivity leading to an improvement in the country's competitive position and hence increasing the growth of output still further" (McCombie, 1983:415).

Other post-Keynesian and structuralist authors (Braun and Joy, 1968; Thirwall, 1979 and 1986) followed a similar path and also considered the relevance of economic structure and the specialization pattern in terms of different income elasticity for exports and imports. By this mean, all these writers, faithful to the Keynesian tradition, have been attributed to demand a key role in explaining growth rates. However, they did not consider the relationship between micro competition and the economic development (Metcalfe, Uyarra, and Ramlogan, 2001). Therefore, their perspective lacks a micro-evolutionary perspective, industrial dynamics and an analysis of the competition process that can account of micro determinants of productivity evolution. Some attempts had been made in other to provide micro foundation to Kaldor model of growth (Boyer and Pettit, 1991 and Llerena and Lorentz 2004, Verspagen 1993 and 2002), nevertheless they were no concerned of development issues.

More recently, several authors belonging to new development economic theory (Amsden, 2004; Ocampo, 2005 and 2009; Reinert, 2007; Ross, 2005; Palma, 2005; Cimoli and Porcile, 2009; Cimoli, Porcile, and Rovira, 2009,) have made important theoretical contributions by combining traditional macro-structure analysis with the new micro-evolutionary foundations of innovation economics. They have criticized the openness and the specialization pattern based on static advantages and decreasing returns. They have shown that the low presence of sectors with high Keynesian and Schumpeterian efficiency in production and trade structure also acts as a constraint to growth. In this case, the problems of specialization are not only related to the macroeconomic effects of international trade but also to the weakness of micro and meso knowledge and technological accumulation derived from feedbacks between international competitiveness and technological capabilities, the lack of exploitation of increasing returns, and the low importance of knowledge complementarities and sectors with steep learning curves in productive structure (Reinert, 1995). In all these cases the micro-macro complementarities and feedbacks are in some sense present in their analysis.

Within a tradition of macro-complexity, the old and new development theories have insisted in the relevance of specialization based on sectors with increasing returns. Nevertheless, in recent years, the development debate seems to have swung back as a consequence of the sharp increase in the prices of food and other industrial commodities. Since then, some suggestions for rescuing the specialization pattern based on natural resources have returned to the scene. This position is followed by the World Bank approach and other international institutions which are slightly different from the '90s Washington Consensus but still remain extremely simple when compared with the old and new development theory mentioned above. For example, according to Lederman and Maloney (2007), "overall natural resource wealth is good for development and becomes a real development asset when coupled with investment in skill and technological capacities and with good macroeconomic institutions and management". Within this view, natural resource–based activities are not a resource curse and that from an econometric perspective natural resource exports have a positive effect on economic growth, especially at the recent juncture of high commodity prices.

Some recent heterodox streams are also linked to this approach (Andersen, 2009, Lorentzen, 2008; Perez, 2008) which has an important background in Ramos's work (1998). Despite the attention that these authors give to the analysis of the characteristics of economic systems such as path dependency, heterogeneity, and learning processes, they remain very close to orthodox analysis, especially with regard to policy implications. According to Perez (2008), the likelihood of Latin America succeeding in high-tech sectors is rather low. Asian countries that managed to catch up took advantage of a window of opportunity that came with the rise of the ICT-based techno-productive paradigm that has now closed. Therefore, Perez stresses that by cleverly exploiting existing advantages of high prices, Latin American countries can become suppliers of material inputs, food, and other agricultural goods oriented to developed countries and exploit their expertise to develop skills and add value.

Although simplistic economics has complicated their arguments, they remain simplistic. As was noted by Ocampo (2009), the growth boom during the early years of the century, was based on a unique combination of four factors that operated positively in the same direction and simultaneously for the first time: high commodity prices, growth in international trade, financial conditions, and exceptionally high levels of remittances. Nevertheless, the emergence of the 2008 crisis showed that these conditions could not be extrapolated into the future. The trade and financial liberalization policies the region experienced in the '90s fostered an increase in import income elasticity that was not offset by a similar increase in the export income elasticity. This issue inhibits the region from successfully catching up with labor productivity in developed countries. Not even the favorable conditions in international prices have been a powerful enough incentive to observe increasing expenditures aimed at developing technological and organizational capabilities, especially in sectors with increasing returns to scale. Interestingly, despite the strong output growth over those years, the productivity gap between the U.S. and Latin America continued to widen (Cimoli et al, 2009), which reflects the absence of catching-up processes even during exceptional development of economic activity in the region.

In this context, the new development authors have an interesting answer to natural-resources arguments by combining structuralism and micro-evolutionary theory (Ocampo, 2005; Laplane et al, 2005; Cimoli and Primi, 2005; Cimoli, Porcile, and

Rovira, 2009; Cimoli and Porcile, 2009; Reinert, 2007). These authors have not only stressed the presence of several structural problems that should be resolved by changing the specialization pattern, but also the relevance of capacity accumulation at the micro and meso levels. As well as justifying the complexity approach, they pointed out the need to consider micro and macro interaction in a non-linear way and the impact of both on divergent development paths.

In this regard, the analytical model that we are going to present in the next section although introduces explicitly the complexity framework remain very close to this branch of literature. The overall framework provided by the theory of complex systems can articulate macro- and micro-complexity to give a new meaning to the question of productive specialization and rethink the design of development-oriented policies. The new development theory starts building bridges between the micro specificities described by evolutionary theory and the macro conditions and macro feedback effect stressed by structuralism. Nevertheless, we think that the complex systems theory will help to provide theoretical bases not only for the integration between micro, meso, and macro dimensions but also to explain the evolution of the whole system as a consequence of the feedback between them.

3. Complex systems approach to innovation economics

The complex systems approach applied to economics and especially to innovation economics has grown enormously during the last few 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, 1987; Silverberg, Dosi, and Orsenigo, 1988; Arthur, 1989; Mirowsky, 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 and 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

[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.

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 and 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] 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 et al, 2005) and changes in technological paradigms (Lane, 2010), following, among other, the ideas of self-organization, far-from-equilibrium dynamics, emergency and self-organized criticality (Prigogine and Stengers, 1985, Kauffman, 1993 and Bak, 1987 among others).

Other group of authors, linked to the economic perspective of the Santa Fe Institute (Arthur, Lane, and Durlauf, 1997; Durlauf and Lane, 1997; Lane and Maxfield 1997; Lane, 2000; 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; Durlauf, Lane, and Mansfield, 1997; and Testfastsion 2003). Others authors linked to the development of a theory of inventions (Lane, 2010; Fleming, and Sorenson. 2001) use fitness landscape models. Some authors consider that the physical percolation model helps understand the complex dynamics of technology adoption (Siverberg 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.

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[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.

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 (macrostructure dynamics explained on the basis of local interactions at the micro level), (iv) ontological uncertainty, (vii) the creative capacity of the system components, and (viii) the existence of order out of equilibrium (attractors).

In this regard, Metcalfe, Foster, and Ramlogan (2006) and Mirowski (1989) 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 expectations of conventional economics, the equilibrium of a system is seen, according to complex systems theory, as a situation of disorder and minimal coordination (Mirowski, 1989).

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

[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.

[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."

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) 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 chapter 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.

4. Complexity and development: an analytical model

This section proposes a theoretical model that accounts for the interaction between creative agents and the development of capacities built upon those interactions within a specific institutional framework. Departing from the complex system approach 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. The presence of non-linear dynamics involved in learning paths explains why the initial differences in the economic development tend to increase.

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. The networks in which firms are embedded constitute the multidimensional space described by Antonelli (2008). Clusters (Humphrey, 1995; Schmitz, 1995 and 1999; Nadvi, 1999), 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, 2001; Greffi 2001) are 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 gradient 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 characteristics in countries with different levels of development. For example, in developing countries, these multidimensional spaces would be poorly integrated, and the lack of complementarities among agents would limit external economies and negatively impact their learning processes. Meanwhile, in developed countries those spaces work as a quasi-market where firms can find shortage competencies. 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 chapter 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 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. These dynamics tend to consolidate institutional frameworks (macro and meso structures) that could be adverse or beneficial to innovation and that reinforce divergent development paths (Stiglitz and Hoff, 2002; Aghion, David and Forey 2008; Rivera Ríos, Robert, and Yoguel, 2009), that in turn,

[9] That involve bridge institutions (Casalet, 2005), gatekeepers (Giuliani and Bell, 2001), club goods, diversity and the possibility to establish complementarities, among other.

would affect the behavior of agents and level of their capacities. As an example, in developing countries adaptive reactions would prevail and therefore the critical mass of agents playing against the rules may not be reached. In this context, there are no forces that provoke institutional change and there would be a consolidation of the institutional framework that is adverse to innovation. Therefore, the institutional framework 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 and 2007; Winter, 2006; Dosi et al 2006; Pisano, 2006; Teece, 1986; Erbes et al, 2006), destructive creation (Schumpeter, 1912, 1942; Metcalfe et al 2002, 2006), and structural change processes (Ocampo, 2005).

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) and dynamic capabilities (Teece and Pisano, 1994). As long as this capacity is developed, creative reactions will predominate over adaptive ones.

Connectivity capacity is associated with the system's potential for establishing relationships and generating interaction with other agents 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, Teece, 1992, Richardson, 1972, Lauren and Salter, 2004; Mowery et al., 1996; Freeman, 1991; Ahuja, 2000; Coombs and Metcalfe, 2000). 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. Ultimately, this ability is what defines how open or closed a system is.

The absorption and connectivity capacities are mutually reinforcing (See Figure 1).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 (Hakansson, 1989; Keinknecht and Reijnen, 1991; Tether, 2002; Belderbos, Carree, and Lokshin, 2004; Veugelers and Cassiman, 2005; Vega-Jurado et al, 2008; Bishop, D'Este, and Neely, 2008; Lee and Eom, 2009; Tsai and Wang, 2009).

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. Meanwhile, in developed countries it is mainly oriented towards R&D, which in turn allow the development of capacities, whereas in developing countries innovation efforts are

mainly embodied in capital goods. 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 (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 and 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. Despite the existence of a bi-directional relationship, it can be argued that absorption capacity is a necessary condition for the development of connectivity (Kleinknecht and Reijnen, 1991; Fritsch and Lukas, 2002; Tether, 2002; Mohnen and Hoareau, 2002; Cassiman and Veugelers, 2002; Miotti and Sachwald, 2003; 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[10].

Therefore, 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. 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 attain an important stage of development in the interconnected processes of creative destruction, appropriation, and structural change (See Figure 1).

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 that enhances innovation will select and reward creative behavior. For this to happen, a critical mass of agents playing against the rule is needed, but it will depend on the extension of markets. In developing countries this extension is lower than in developed ones, which in turn is favored by the low export coefficient in sectors with increasing returns. While the selection

[10] 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.

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 et al, 2003 and Metcalfe et al 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.

The **appropriation process** (Cohen, Nelson, and Walsh, 2000; Antonelli, 1997 and 2007; Winter, 2006; Dosi et al 2006; Pisano, 2006; Teece, 1986) 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 competition and the demand regime. 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 et al, 2002). 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 and the scope of the markets. Nevertheless, these rules can change according to agents' reactions. Regarding appropriation processes, we account for intentional rent-seeking behavior in agents.

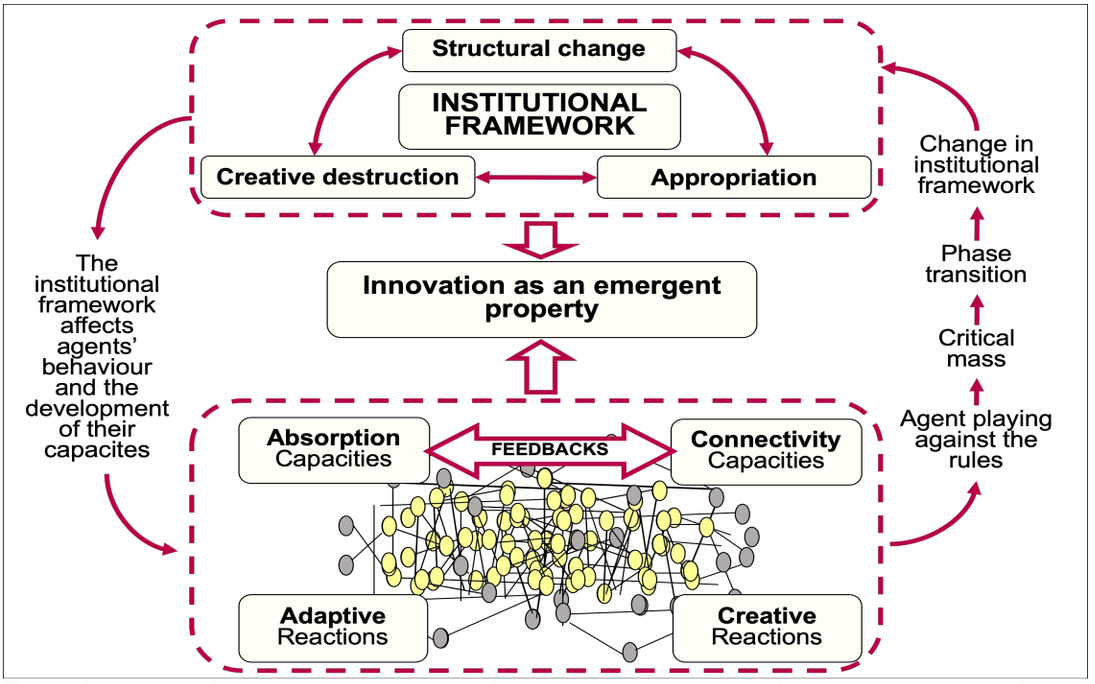
Finally, the **process of structural change** (Ocampo, 2005) describes changes in productive structure that make it more diversified, better integrated, and, thus, more developed. In this sense, the process of structural change involves both a specific direction of change and also, as a consequence, development issues. This process is very close to development theories. It 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, from a strategic point of view, the process of structural change is not spontaneous, but is the result of development policies which imply that players are able to define their behavior in a game in which coordination and information are problems to be solved (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 of the new development stream mentioned above.

The 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 more complex innovative activities 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 developing countries, where adaptive reactions prevail, economic development is conditioned by the system's capacity for appropriating knowledge and performing innovative processes.

The degree of development of these processes that jointly explain the main characteristics of the institutional framework is conditioned by the level reached by absorption and connectivity capacities and the feedback mechanisms between them. Therefore, the building of capacities as well as the behavior of agents in terms of adaptive or creative reactions determines the innovation activity of the system and the evolution of the processes of appropriation, creative destruction and structural change. Any system requires not only internally produced knowledge but also knowledge derived from relationships establish within the multidimensional space. 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.

Figure 1. Analytical model



The relationship between capacities and processes is reciprocal and it is reinforced over time. 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 between capacities and processes. Only the creative reaction of agents, through innovation process, would make changes on the structure of quasi-rents. Nevertheless capacities are also conditioned by the features that the three processes assume. In this way, the specialization pattern would limit the innovative activity due to the lack of technological complementarities present in economic systems characterized by structural dualism. Meanwhile, the processes of appropriation and creative destruction define the basis on which economic agents must compete, develop their capacities and generate innovations. In sum, the

three processes describe evolution in the institutional framework and then establish the conditions for the appearance, or the blockading, of creative reactions.

From this perspective, more complex economic systems tend to develop creative capacities that drive changes in the system and in the developing path. 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 limit or foster 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 development 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.

5. Capacities and processes: the specificities of economic development

In the previous sections we have defined the complexity of an economic system in relation to the level and evolution of capacities and processes and the interactions between them. Following the stream of the new theory of development that combines structuralist and micro-evolutionary approaches (Ocampo, 2005; Laplane et al, 2005; Cimoli and Primi, 2005; Cimoli, Porcile, and Rovira, 2009, Cimoli and Porcile, 2009; Reinert, 2007, Chang, 2009), we propose that these relationships operate differently in developed, newly industrialized, and developing countries[11]. Thus, whereas in more complex economic systems, capacities and processes enhance their development path, in the opposite case, different kinds of blockades would limit the feedback between firms' capacities, while the weakness of the processes would constrain the development of capacities (see Box 1). In this sense, in developing countries, the interaction between micro and macro dimensions operates by blockading the feedback mechanisms that foster capacities and provoke reactions against the rules among economics agents. As long as the critical mass of agents playing against the rules cannot be reached, the necessary phase transition does not occur and the institutional framework adverse to innovation continues shaping adaptive reactions. As a consequence, the productive structure in developing countries can be characterized by: (i) an income import elasticity higher than income export elasticity (ii) low complementarities between activities and structural dualism, (iii) scarcity of agents' innovation propensity, (iv) low importance of disembodied innovation efforts, (v) a specialization pattern in low knowledge–intensive products and (vi) a weak position in the global value chains and networks they belong to, limiting the appropriation of externalities and knowledge. Therefore identifying the blockades between the micro and macro interactions becomes

[11]We are referring to Latin American countries from here on.

the key question for development theory (Cimoli and Porcile, 2009) and for the design of development policies (Reinert, 2007).

Regarding 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. The differences would result in the existence of countries with uneven developmental potential, because the lack of complementarities between capacities would act as a blockade in feedback dynamics and in the number of agents playing against the rules. Therefore, the structural heterogeneity (Ocampo, 2005) would limit the linkages between firms and thus the multidimensional space 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. (See Box 1 for references to capacity building in developed and developing countries).

In turn, the main characteristics of the processes are manifested in the degree of diversification of the specialization pattern, the presence or not of sectors with increasing returns and the extent in which the competition process rewards innovation. 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 the processes. But also, these processes condition the building of capacities. Therefore, innovation is an endogenous result of feedback between capacities and processes. Its relevance would depend also (i) on the relationships between processes and their influence on capacities, (ii) on the feedback effects between capacities, (iii) on the number of agents playing against the rules that threaten the established position of quasi-rents, and (iv) on the system capacity to counterbalance the possible blockades to develop positive feedbacks that rise agent capacities. In this regard, when these dimensions are relevant the economic system goes through a phase transition that enables institutional changes and development. (See Box 2 for some innovation statistics in developed and developing countries.)

In developed and newly Asian 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. 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 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 (see Box 1).

Box 1 Capacities and feedback in developed and developing countries

The relation between firms' capacities and linkages has been studied by several authors and in most of cases statistical relationships between these dimensions were found. For example, in developed countries (mainly European countries), a set of papers have found that absorption capacity is a key determinant in R+D cooperation (Kleinknecht and Reijnen, 1991; Fritsch and Lukas, 2002; Tether, 2002; Mohnen and Hoareau, 2002; Cassiman and Veugelers, 2002; Miotti and Sachwald, 2003). Other authors assume that the relationship is bidirectional, which means the existence of feedback effects (Veuglers, 1997; Becker and Dietz, 2004; Vega-Jurado et al, 2008; D'Este, and Neely, 2008) Others analyze how both absorption and connectivity determine the level of innovativeness in firms (Belderbos, Carree, and Lokshin, 2004, Nieto and Santamaría, Caloghirou, Kastelli, and Tsakanikas, 2004; Miotti and Sachwald, 2003; Vega-Jurado et al, 2008). In the cases of Korea and Taiwan, some papers have found that internal R&D and the acquisition of external knowledge (outsourcing and cooperation) impact innovation Eom and Lee (2009), Tsai and Wang (2008). For Latin American countries, the literature stresses that absorption capacities act as a barrier in the access to connectivity, blockading the feedback mechanisms. Nevertheless, when this happens it has a positive effect on innovation. Therefore, the literature for Latin American countries does not deny the existence of agents that have reached high levels in their absorption and connectivity capacities but are not enough to achieve the critical threshold required to trigger processes of structural change (Bianchi, Grass, and Sultz, 2008; Garrido and Padilla, 2008; Benavente and Padilla, 2008; Kupfer and Avellar, 2008: Arza and Lopez, 2008; Erbes, Robert, and Yoguel, 2010).In sum, in developed countries firms' connectivity is oriented mainly to R&D. Besides, in spite of the kind of causality, there is a great difference between these connectivity capacities and those of firms belonging to developing countries.

In these 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 appropriation of knowledge generated in the form of quasi-rents derived from increasing returns. In sector with Schumpeterian efficiency, 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, 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 relevant disembodied innovation efforts, and strong synergies between sectors that are possible through complex translation mechanisms between agents (Stokes, 2003). 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. In the case of successful economic performance of some East Asian countries Chang (2002, 2009) demonstrates that it depends (i) on the change of specialization pattern towards knowledge intensive sectors, (ii) on the support to the infant industry, and (iii) on the key role of industrial and technological policy allowing them to leave a Ricardian or Herscher-Ohlin specialization pattern.

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 of 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 Latin American countries, in contrast, the search for new combinations that are oriented towards the generation of innovations aimed at increasing variety and improving selection is less relevant in competition. Learning and technological processes have mainly been embodied and they are poorly fuelled by knowledge derived from basic and applied science. (See Box 1.)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 themselves. 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.

In explaining the innovation results by means of absorption and connectivity capacities, in Argentina, Erbes, Robert and Yoguel (2010) find some evidences that exemplify firms' behavior in Latin-American countries. These authors 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.

Therefore, as has been illustrated by old and new development theory, in developing countries 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 (Erbes et al, 2006).

Finally, 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 (see Box 2). 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 characterize by high income elasticity of imports and low income elasticity of exports blockade the feedback effect between product and productivity and the dynamics implicit in the Kaldor-Verdoon relation. As was shown before, this specialization pattern would condition the development system component capacities.

Box 2. 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 developed countries (on average for the selected countries show in table 1). 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 expenditure /GDP	3. % of private R&D over total R&D	4.Reseach-ers per million inhabitants	5. % Tertiary enrollment 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	3353	8	0.7	26,169	204
Germany	119	2.52	70	3386	7	0.69	25,610	115*
Italy	25	-	-	-	4	0.39	23,174	226
Japan	267	3.4	77	5546	8	1.16	24,660	432
United Kingdom	57	1.8	62	3033	10	1.21	26,762	158
United States	279	2.61	70	4651	6	1.1	36,100	177
Spain	7	-	-	-	6	0.4	20,973	322
China	0.5	1.42	71	926	1	1.69	5,333	1,099
Korea	114	3.23	77	4162	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	0.5	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).

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 (2009) have shown, the nonexistence of convergence and the problems linked to a deficit in 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” and because there is not a convergence of economic structures.

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 low 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 return, competition based on prices in highly volatile markets, a demand for unskilled labor, the use of low-quality processes, and mainly embodied technical progress. Latin American 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[12].

These processes are poorly fueled by knowledge derived from basic and applied science and from firms' linkages with the environment, especially with universities and technological centers. Finally, 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 (see Figure 1).

Therefore, because of the low complementarities between agents derived from the prevalent specialization pattern, systemic dimensions are weak 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 and 2007; Rodrik, 1999).

This evidence reveals relevant differences between Latin American and Asian countries. In this regard, Cimoli, Dosi, and Stiglitz (2008) stress that only the later have made the transition from production capacities to the technological capacity required for generating technical change.

The presence of these patterns in Latin American countries can be then be understood from a complex system approach which stresses that the absence of convergence discussed in the third section is not only derived from the low level and limited feedback between processes but also from the issues associated with a low level of absorption and connectivity capacities and limited or absence of feedback between them. Meanwhile, the blockades to theses feedbacks and the absence of a critical mass of agents playing against the rules would explain why the level and composition of the innovation as an emergent property of the system is insufficient to overcame the productivity gap with developed countries.

[12] 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.

6. 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[13]. 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 structural 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 becomes 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[14]. 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.

[13]The creation of pathways for positive feedback are stressed by David and Aghion (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).

[14]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.

In this sense, industrial and technological policies should take into account some of the issues discussed in this chapter 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 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 (David et al 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.[15] 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 account. 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.

[15]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 and Braidot, 2007), (iii) post-Taylorist forms of work organization (Delfini, Roitter and Pujol, 2007) and a significant increase in the role of design as a source of quasi-rents (Silva et al, 2008).

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 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 sectors through the selection of those 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 chapter 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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