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3. Venture capitalism as a mechanism for knowledge governance¹

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1. INTRODUCTION

New dedicated capital markets specialized in the public transactions of the stocks of ‘science-based companies’ emerged in the USA during the 1970s. These new financial markets enable the anticipation of returns stemming from the economic applications of technological knowledge, bundled with managerial competence, but non-embodied in either capital or intermediary goods. As such the financial markets have, for the first time in history, promoted the creation and growth of a specialized segment of ‘inventor’ companies and favored public transactions in technological knowledge as an activity *per se*.

These new financial markets are becoming a key component of an innovation-driven novel institutional system termed ‘venture capitalism’. This is key for a new model of ‘knowledge-based’ growth relevant not only for information and communication technologies but also for biotechnologies and new radical technologies at large (Perez, 2003).

As such, venture capitalism can be considered a major institutional innovation that enables higher levels of knowledge governance. The basic ‘innovation’ here is not technological but rather institutional, as it consists in a new hybrid organization based upon the bundling of knowledge, finance and competence into new science-based startup firms and in the trade of their knowledge-intensive property rights in dedicated institutional financial markets (Hodgson, 1998; Menard, 2000, 2004; Menard and Shirley, 2005).

In order to grasp the process that has led to its introduction we shall rely upon the complexity approach to the economics of innovation. The application of the tools of complex system dynamics to the economics of innovation enables us to analyze the role of new multi-agent structures such as the new financial markets characterized by higher-level organizations. These ‘higher levels of organization’ in fact are forms of organized complexity that favor the generation and dissemination of technological

knowledge into economic systems. Specifically venture capitalism can be considered a major institutional innovation that provides a platform for the more effective exploitation of technological knowledge bringing together into a coalition for innovation a variety of complementary players such as ‘inventors’, venture capital companies, managerial skills and investment funds, large incumbents searching for new sources of technological knowledge and families looking for new financial assets, and stirring their participation and active contribution to a collective undertaking (Lane, 1993; Lane and Maxfield, 2005; Antonelli, 2008; Lane et al., 2009).

This work elaborates the view that venture capitalism has improved the governance of technological knowledge within economic systems, and hence has reshaped the prime mechanism by which the generation of new knowledge can lead to economic growth (Nelson, 1994, 1995; Quéré, 2004).

The rest of the work is organized as follows. Section 2 and 3 provide the analytical background. Specifically, Section 2 provides the basic economics of the relationship between finance and innovation, and highlights the advantages of the new financial markets in providing funds to science-based startup companies with respect to previous institutional arrangements such as banks and incumbent corporations. Section 3 explores the basic elements of the economics of markets as economic institutions. Section 4 shows the complexity of interactions that led to the emergence of the new financial markets. The conclusions highlight the main results.

2. FINANCE AND INNOVATION: THE FRAMEWORK

Knowledge as an economic good exhibits major limitations in terms of radical uncertainty, non-divisibility, non-excludability, non-exhaustibility, non-appropriability and non-rivalry in use. Much economic analysis has explored the implications with respect to the tradability of knowledge (Arrow, 1962). Yet the limitations of knowledge as an economic good have major implications also in terms of the provision of finance to fund its generation and use.

Major asymmetries shape the interaction between prospective funders and prospective innovators. The access to financial markets for innovative projects is seriously limited by the radical uncertainty that characterizes both the generation and the exploitation of new knowledge. Prospective lenders and investors are worried by the combined high levels of risk: (1) that the activities that have been funded with their own money will not succeed, and (2) that the new knowledge, occasionally generated, will

not be appropriated by the inventor, at least to an extent that makes it possible to repay the credits and remunerate the capital invested. Even in the case of a successful generation, funders have good reasons to worry about dissipation stemming from uncontrolled leakages of proprietary knowledge. As a consequence, worthy inventive activities and innovative projects risk being jeopardized because of the lack of financial resources (Hall, 2002).

Stiglitz has provided two fundamental tools to analyze the relationship between finance and innovation. With the first stream of contributions, Stiglitz (Stiglitz and Weiss, 1981; Stiglitz, 1985) has shown that equity finance has an important advantage over debt in the provision of funds to innovative undertakings because investors have the right to claim a share of the profits of successful companies. While lenders can claim only their credits, investors can participate to the bottom tail of the highly skewed distribution of positive returns stemming from the generation of new knowledge and the introduction of new technologies. This has important consequences in terms of reduction of both the risks of credit rationing and the costs of financial resources for research activities. Lenders need to charge high interest rates in order to compensate for the risks of failure and to discriminate among new research activities to avoid as many 'lemons' as possible. Equity investors instead find an equilibrium rate of return at much lower levels because they can participate in the huge profits of a small fraction of the new ventures. The fraction of lemons that equity can support is much larger than that of debt, hence financial equity can provide a much larger amount of funding for research activities.

With a second line of analysis, Stiglitz (Sah and Stiglitz, 1986, 1988) has provided the distinction between hierarchies and polyarchies as alternative mechanisms to manage different types of risk. Hierarchical decision-making is better able to avoid the funding of bad projects. Yet the ability of hierarchies is limited by the scope of their competence: their decision-making tends to favor minor, incremental changes. Polyarchic decision-making, on the other hand, experiences higher risks of including bad projects, for example Type 1 errors, but yields higher chances of inclusion of outstanding projects. According to Stiglitz, hierarchical decision-making fits better in economic environments characterized by low levels of entropy and radical uncertainty. Conversely, polyarchic decision-making applies better in times when the levels of radical uncertainty are higher.

The distinction between Type 1 and Type 2 errors proves very useful in assessing the working of alternative mechanisms and forms of decision-making in the selection and implementation of new technological knowledge. The argument elaborated by Stiglitz can be used upside-down so as to investigate what type of decision-making yields higher results in

terms of the generation of new technological knowledge and the eventual introduction of innovations.

Hierarchies are more likely to incur Type 2 errors that arise when good innovative projects are excluded. Hence hierarchical decision-making has higher chances of favoring incremental innovations and to excluding innovative undertakings that are disruptive and may engender problems in terms of discontinuities both with respect to the existing knowledge base and sunk costs. Polyarchic decision-making, based on a variety of competences, selected on a professional basis according to their expertise, and less exposed to vested interests, on the contrary, favors the inclusion of a wider range of projects. As a consequence, polyarchies tend to include also bad projects. But the likelihood that outstanding projects are retained is much higher. The occurrence of radical innovations seems higher with polyarchic architectures.

The combination and implementation of the two tools provided by Stiglitz enable the comparative assessment of the alternative institutional mechanisms designed to handle the relationship between finance and innovation, and identified by Schumpeter: banks and corporations. The analysis of their limitations, with the tools provided by Stiglitz, enables us to identify the emerging venture capitalism as a third distinctive mechanism.

In his *Theory of Economic Development*, Schumpeter stresses the central role of the provision of appropriate financial resources to entrepreneurs. The natural interface of the entrepreneur, as a matter of fact, is the innovative banker. The banker is innovative when he is able to spot new opportunities and select among the myriad of business proposals that are daily submitted, those that have higher chances of getting through the system. With a given quantity of financial resources, the innovative banker should be able to reduce the flow of funds towards traditional activities and switch them towards the new firms. The innovative banker should be able to identify the obsolete incumbents that are going to be forced to exit by the creative destruction that follows the entry of successful innovators.

Banks can be considered much closer to polyarchic decision-making. They can rely upon a variety of expertise and competence, hired on a professional basis. Their competence is much less constrained by a given scope of expertise, and the effects of irreversibilities and vested interests are much lower. As such, banks seem better able to avoid Type 2 errors. Banks have a clear advantage in the screening process, but their action is limited by clear disadvantages in the participation in the profits stemming from new innovative undertakings. Banks are exposed to the intrinsic asymmetry between debt and equity in the provision of funds to innovative undertakings. This is true especially when radical innovations occur. The higher the discontinuity brought about by radical innovations, the

larger the risks of failure of new companies. Banks bear the risks of the failure of firms that had access to their financial support but cannot share the benefits of radical breakthroughs. As Schumpeter himself realized, this model, although practiced with much success in Germany in the last decades of the nineteenth century, suffered from the severe limitations brought about by this basic asymmetry.

Schumpeter not only realized the limits of the first model but identified the new model emerging in the US economy at the beginning of the twentieth century. The analysis of the corporation as the institutional alternative to the 'innovative banker' has been laid down in *Capitalism, Socialism and Democracy*. Here Schumpeter identifies the large corporation as the driving institution for the introduction of innovations. His analysis of the corporation as an innovative institutional approach to improving the relationship between finance and innovation has received less attention than other facets (King and Levine, 1993). The internal markets of the Schumpeterian corporation substitute external financial markets in the key role of the effective provision and correct allocation of funds combining financial resources and entrepreneurial vision within competent hierarchies. Corporations, however, are much less able to manage the screening process. Internal vested interests and localized technological knowledge help reduce the risks of funding bad projects but risk reducing the chances that radical innovations are funded.

The Schumpeterian corporation confirms that equity finance is more effective than debt finance for channeling resources towards innovative undertakings, but with a substantial bias characterized by continuity with the existing knowledge base. The model of finance for innovation based upon the corporation ranks higher than the model based upon banks in that equity finance is more efficient than debt-based finance with respect to risk-sharing, but has its own limitations arising from the reduction of the centers able to handle the decision-making and the ensuing reduction of the scope of competence that filters new undertakings.

In the second part of the twentieth century a few corporations concentrated worldwide a large part of the provision of finance for innovation. The limited span of competence of a small and decreasing number of incumbents became less and less able to identify and implement new radical technologies: a case of lock-in competence could be observed. The corporation has been able for a large proportion of the twentieth century to fulfill the pivotal role of intermediary between finance and innovations, but with a strong bias in favor of incremental technological change. The screening capabilities of corporations fail to appreciate radical novelties.

The integration of these two strands of analysis highlights the radical mismatch between the distinctive competence and the competitive advantage

of the two traditional modes of provision of financial resources to innovation. Both in equity and debt finance, exploitation conditions on the one hand and competence on the other, are not aligned and are actually divergent. Banks, as polyarchies, are better able to identify and fund radical innovations but cannot participate into their extraprofits, as they provide debt and not equity. On the contrary they are exposed to the high rates of failures stemming from type 1 errors, for example, the higher incidence of 'lemons' into their portfolios of funded projects. Corporate provision of funds to internal R&D projects selected by internal and hierarchical decision-making is less inclined to identifying and funding radical innovations that would benefit larger firms as equity providers. Corporations are better able to fund minor, incremental innovations where their competitive advantage in exploitation is lesser because the latter are less likely to earn extraprofits. This misalignment between the distinctive exploitation conditions and the intrinsic competence of the two traditional institutions has the clear effect of reducing the incentives to the provision of funds for innovation, and of increasing the interest rates for debt finance. Together with the limits of knowledge as an economic good, this institutional misalignment is one of the main causes of underinvestment in the generation of technological knowledge and hence undersupply of innovations.

A mechanism based upon a screening procedure performed by competent polyarchies and the equity-based provision of finance to new undertakings would clearly combine the best aspects of each model. Venture capitalism seems more and more likely to emerge as the third major institutional set-up able to manage the complex interplay between finance and innovation when radical changes take place. As a matter of fact, venture capitalism combines the advantages of distributed processing typical of polyarchies with the advantages of equity-based finance over debt-based finance. Venture capitalism makes it possible to combine the more effective identification of radical innovations with the more effective sharing of risks associated with the provision of funds.

Table 3.1 provides a synthetic account of the analysis conducted so far. The bank-based provision of funds to innovation suffers the limits of debt-based finance but ranks higher in terms of distributed processing. The advantages of distributed processing are larger, the larger the number of banks, and the larger the number of independent agents that participate in the screening process. The corporation model is less able to avoid Type 2 errors but enjoys the advantages of the equity-based provision of finance to innovation. The corporation model suffers especially from the grip of the past that sunk costs and the irreversibilities of tangible and intangible capital exert upon the appreciation of new disruptive technologies. It is also clear that the smaller the number of corporations that control the

Table 3.1 Limits and advantages of alternative financial systems for innovations

	Polyarchies	Hierarchies
Debt finance	Banks experience more type 1 errors funding bad projects because of low competence levels but favor the introduction of radical innovations; as lenders however they cannot participate into their extraprofits	
Equity finance	Venture capitalism favor the introduction of radical innovations and participate into the fat tails of profits of new ventures	Corporations can participate into the fat tail of profits of new ventures, and are better able to sort out bad projects, but are limited by higher probability to commit type 2 errors reducing the rate of introduction of radical innovations

funding of innovative undertaking, the higher the risks of Type 2 errors at the system level. Venture capitalism seems able to combine the advantages of the corporation model in terms of equity-based provision of funds for innovation, with the distributed processing typical of the banking system.

The emergence of the new, dedicated financial markets specialized in the public transactions of the knowledge-intensive property rights of new science-based startup companies is a key aspect of venture capitalism. As such it requires a dedicated analysis.²

In order to grasp the emergence of the new financial markets specialized in the transactions of knowledge-intensive property rights, it is necessary to revisit the basic elements of the economics of markets.

3. MARKETS AS ECONOMIC INSTITUTIONS

Markets as an Economic Problem

Markets are economic institutions that emerge when an appropriate combination of complementary conditions occurs. Markets are the product of social and institutional change. As such, they evolve over time: they

can decline and emerge. At each point in time, markets differ. Markets can be classified according to their characteristics and their functionality. The emergence and upgrading of a market is the result of an articulated institutional process that deserves to be analyzed carefully.

There are three basic notions of market in the literature: (1) in the textbook theory of exchange, markets exist and are self-evident; and any transaction presupposes the existence of an underlying market; (2) markets as devices for reducing transaction costs (Coase); (3) markets as social institutions promoting division of labor, innovation and economic growth.

A major contribution to the discussion of markets comes from Coase whose work clarifies both (1) and (2) above. 'In mainstream economic theory the firm and the market are for the most part assumed to exist and *are not themselves the subject of investigation*' (Coase, 1988, p. 5; italics added). By mainstream economic theory Coase means an economic theory without transaction costs. Transaction costs are the costs of market transactions that include 'search and information costs, bargaining and decision costs, and policing and enforcement costs' (Dahlman, 1979, quoted by Coase), which, of course, includes the costs of contracting. In Coase's theory, transaction costs exist and can be important; and they explain the existence of the firm.³

In the old neoclassical theory of exchange that Coase refers to, the existence of markets (and also the creation of new markets) is assumed but not analyzed. It is an axiom, a self-evident truth, similar to Coase's criticism of the notion of consumer utility, which is central to the above theory: 'a non existing entity which plays a part similar, I suspect, to that of *ether* in the old physics' (Coase, 1988, p. 2; italics added). This view of markets implies that any transaction assumes an underlying market, or that there is no such thing as a transaction without a market. This is not only not correct but, following Coase or the implications of his analysis, we assert that the distinction between individual transactions and a market is important.⁴

For our purposes, markets are social institutions where at least a critical mass of producers and a critical mass of consumers interact and transact. There is an important element of collective interaction and of collective transacting; that is, any one transaction takes into account the conditions of all other transactions.

From this viewpoint a market contrasts with an institutional context characterized by three relevant conditions. First, it is a lower set of transactions than that of the subsequent market. Second, transactions are isolated and sporadic, both synchronically and diachronically. Third, agents do not rely upon exchanges but on self-sufficiency; that is, users produce the products they consume/use.

Originally markets were defined only in geographical terms as locations where a large number of sellers and buyers would meet to trade. Since then, markets have grown into sophisticated institutions characterized by an array of functions and characteristics.⁵ The extent to which the process has grown differs. Different stratifications of institutional evolution can be found according to the characteristics of products and agents involved (Menard, 2004). Markets differ across countries, industries and contexts. Markets differ according to the functions they can perform and their structural characteristics. The emergence and evolution of markets is the result of a process that takes place over time and is shaped by institutional innovations of different kinds.

Towards a Classification of Markets

Markets have properties and characteristics. According to such characteristics, markets are more or less able to perform their functions. The properties of markets do not coincide with the properties of the products being exchanged and the characteristics of agents engaged in trade. Yet there is a high degree of overlap between the characteristics of the products and agents and the properties of the markets.

The reputation of agents is an essential condition for the emergence and the working of markets. The certification of agents and the *ex ante* assessment of their reliability and sustainability provide both tentative customers and suppliers with information necessary to perform transactions. Without the provision of information about the reliability of partners in trade, both customers and suppliers must bear the costly burden of relevant search and assessment activities. From the viewpoint of the effective working of the marketplace, moreover, the symmetric distribution of reputation, as a carrier of information, plays a key role. It is clear that in a system where reputation is distributed unevenly, transactions are likely to privilege the few agents that enjoy the advantages of good reputation. A star system is likely to emerge, with clear monopolistic effects. Systems where the reputation of agents is certified are likely to work better than systems where reputation is asymmetrically distributed. The latter systems, in turn, perform better than systems where average levels of reputation are low. Reputation is a key element in the definition of social capital precisely for its positive effects in terms of reduction of transaction costs.

Products differ widely with respect to their characteristics, and exhibit different levels of general tradability and hence influence the performances of the corresponding markets with respect to the number and quality of the functions provided to the rest of the system.

In this context it is consequently clear that a central property is the

category of products that are being exchanged. We can identify markets built around a specific need category or user segment (encompassing many different products and technologies); and markets built around a particular industry or segment of producers (encompassing many user segments and need categories). In the first profile of a market, users of substitute products relating to the satisfaction of a basic category of need converge; in the second, producers of products related to a basic set of technologies converge. In the former market, the products traded are substitutes on the demand side. In the latter market, defined by a particular producer technology category, for example the chemical industry, the products traded are substitutes on the supply side.

Beyond the characteristics of the products being exchanged in the marketplace, and of agents engaged in trade, we can identify at least six main characteristics of markets: the time horizon of markets plays a central role. Spot markets are far less effective than regular markets. In effective markets, future prices can be identified and a full intertemporal string of prices and quantities can be set. Market density is defined by the number of agents both on the demand and on the supply side. It is clear that markets with one player either on the demand or the supply side are highly imperfect. Market thickness is relevant both on the demand and the supply side with respect to the volume of transactions. With respect to thickness, there is an important issue about the levels of the critical mass necessary for a good performance of the market. When transactions take place with high levels of frequency, the users of markets, both on the demand and the supply side, and prices and quantities can adjust swiftly to changing economic conditions. Sporadic transactions limit the performances of markets. Recurrence of transactions is most important to reduce opportunistic behavior and to make comparisons possible. Recurrence of transactions is a major source of transparency and hence information. The concentration of transactions increases the density, thickness, frequency and recurrence of transactions: as such it can be enforced by means of compulsory interventions, or emerge as the consequence of a spontaneous process. The role of concentration is vital for the emergence of new effective markets, and hence it is at the same time a prerequisite and a threshold factor.

The Functions of Markets

Markets differ greatly with respect to their characteristics, and as a consequence with respect to the functions they can perform. A well-functioning market is able to perform a variety of functions that a set of isolated transactions cannot. At least four basic functions can be identified:

1 Markets as signaling mechanisms to actual or potential users or suppliers/producers

Markets with appropriate levels of thickness and robustness signal to the rest of the economy the need for the specific products being traded; and that the need-satisfying category of good not only exists but is traded and therefore accessible. The signaling involves a qualitative dimension (the ‘need’ and the ‘product class’ satisfying it) and a quantitative dimension reflected in quantities and values purchased and sold. Existence of a market also minimizes volatility and swings concerning persistence of the ‘need’ or possibility of obtaining the good. This is because a market or an industry operating in it is presumably more stable than a single user or a single firm; and a market – compared to a single transaction – provides relative assurance about the possibility of repetitive transactions, purchases or sales, in the future. Signaling existence and persistence of need to be satisfied and product class to be supplied helps any firm/supplier and any user/consumer respectively, actual or potential, to focus his or her search process on the relevant space where the market exists or operates. It also facilitates users’ (producers’) long-run decisions concerning purchase (sale) of a new particular product class or service or system traded in a particular market (‘the product’). The decisions involve investment decisions concerning or involving the product or its supply. Nobody wants to create dependence on a product purchased (sold) whose sources of supply (demand) and mechanisms of purchase (sale) are not highly reliable and stable.⁶

2 Markets as selection and incentive mechanisms

Markets are able to perform relevant screening functions when many different products, manufactured with different technologies, are being confronted. Best products emerge and lower-quality products are screened. The extent to which selection is dynamically efficient depends on characteristics of users, for example on whether or not users are willing or not to take risks in trying novel products. It also depends on characteristics of producers, for example whether they are innovative or not and whether or not competition (as a process) among producers both generates variety and leads individual firms to rapidly adapt and improve their products in response to other firms’ products. Good selection mechanisms enable the allocation of effective incentives to agents, via entry, expansion and invention/innovation, and symmetrically exit when losses emerge both on the demand and the supply side.

3 Markets as coordination mechanisms

By means of their signaling functions, markets make possible coordination in the production of complementary products. Specialization

of agents in the narrow spectrum of activities where each firm has a competitive advantage can be done by means of efficient markets. This because in the market all the relevant users are present, so that a firm can easily know the potential market for that specific component (or components) in the production of which it enjoys a competitive advantage (it will also save on selling costs). The mechanisms in operation seem to be: signaling and selection with interactive learning. More generally, markets facilitate both specialization and integration by producers. Moreover, markets also provide integration opportunities on the demand side: they facilitate integration and specialization of users that can combine specialized products into more elaborated consumption and usage.

4 Markets as risk management mechanisms

By reducing transaction costs and through the enhancement of variety of firms and products, some markets (as opposed to transactions without markets) make possible the distribution of risks across a variety of firms and products. Hence they reduce the risks of opportunistic behavior and information and knowledge asymmetries.

Only a few markets can reach all the necessary levels of time horizon, density, thickness, frequency, recurrence and concentration. The analysis of the broad array of characteristics and functions of markets as economic institutions enables the analysis of the emergence of the market as the result of a process of convergent and complementary innovations. Markets emerge and consolidate as specialized institutions.⁷

From this viewpoint, the emergence of a viable market can be considered the result of an articulated, institutional process that deserves to be analyzed carefully. Markets are social institutions that perform a variety of functions and exhibit different forms, organizations and characteristics. Moreover, markets are a dynamical construct.

Hence markets are being created, they emerge, occasionally their performances and functions improve, yet they can decline. In other words, markets evolve (Richter, 2007).

In turn, the emergence of new specialized markets has an impact on the economic system. This leads us to appreciate the notion of 'market' originally proposed by Adam Smith, namely 'a device that promotes division of labor, learning/innovation, and economic growth'.

An effort to understand the institutional characteristics of markets in a general context seems necessary in order to grasp all the implications of the creation of the new financial markets associated with venture capitalism. The analysis of their emergence should be the center-piece in any theory of economic development nowadays: markets perform a central role not

only in the allocation of resources but also in promoting 'knowledge-based growth' (De Liso, 2006).

4. THE EMERGENCE OF NASDAQ FOR VENTURE CAPITALISM

The creation of a surrogate market for knowledge where knowledge-intensive property rights can be traded as financial products can be considered one of the key features and contributions of venture capitalism. The new financial markets specialized in knowledge-intensive property rights are based on a new intermediation form that emerges from the mutual adaptation of different groups of actors both on the supply and the demand side, and with the underlying institutional structure. This has led to a multilayer super-market such as NASDAQ, which enables participants to relate to a large number of markets for individual stocks simultaneously, thereby better coordinating their needs with the capabilities offered.

A new market may emerge when a set of previously isolated precursor transactions sparks an emergence process. For this to happen, a number of conditions are required. Frequently these will include pre-emergence processes of interaction and information flow among agents, together with experimentation and learning concerning product characteristics and user/producer organization and strategy. Emergence may also require a critical mass of precursor transactions both to underpin the above-mentioned interactions, learning and experimental processes, and to enhance the expected 'benefits' derived from creating a new market.⁸ Moreover, the successful emergence of a new market may depend critically on the converging action of agents towards emerging platforms able to providing the required dynamic coordination (Richardson, 1972, 1998).

The evolutionary process leading to the emergence of a new market is seen as an autocatalytic, cumulative process with positive feedback, or, alternatively, a process characterized by dynamic economies of scale. This process involves the creation and utilization of externalities that explain the acceleration of growth. The cumulative process does not end with creation of the new market; rather it continues afterwards at least for a time (provided that external conditions do not deteriorate).⁹

The new (more complex) structure created by the interaction among elementary components (firms and users) will, once it is emerged, positively further stimulate such components. This phenomenon provides us with an additional, and much less recognized, characteristic of 'a market': once created it will stimulate the creation of new firms.¹⁰

The Phases of the Process

The emergence of the new financial markets is the result of a continued process of convergent and complementary steps that can be visualized as comprising four phases.

Phase I. Bundling finance and competence with innovation

Since the early days, venture capital firms specialized in the provision of 'equity finance' to new science-based startup companies as distinct from 'loans', which were the prevailing product offered by existing financial institutions (banks). Equity finance was offered to science-based startup companies bundled together with business services and management advice, management services, certification and networking functions. This was exchanged for limited partnership. Limited partnership is a key 'precursor' dimension to the emergence of the new market. In the USA during the 1960s and 1970s, limited partnerships were the dominant form of organization for new science-based startup companies. Limited partnership allowed for dilution of founder equity positions and a capital (jointly with the prevailing product) market orientation.

Gompers and Lerner (1999) stress the role at this stage of the changing features of intellectual property right regimes. The increasing depth, width and duration of patents has led to higher levels of appropriability for knowledge that is embodied in new science-based companies, and traded the form of knowledge-intensive property rights rather than bundled within large diversified incumbents. Large incumbents were able to rely much less of the protection provided by intellectual property rights because of the advantages of existing barriers to entry that would delay the dissipation of innovation rents. Large incumbents, moreover, can take advantage of lead times and secrecy as effective mechanisms of knowledge appropriation. New science-based startup companies, on the other hand, need to disclose information about the advantages of their knowledge base: patents perform a key signaling function. The protection of hard intellectual property right regimes is much more important for science-based startup companies that are newcomers themselves. The radical changes in intellectual property right regimes introduced in the 1980s and 1990s clearly favored venture capitalism because they reduced for investors the levels of risks associated with the non-appropriability of the strong knowledge component of the intangible assets of the new science based firms (Hussinger, 2006).

Phase II. Knowledge-intensive property rights

Phase II is marked by the evolution of limited partnership as the leading form of organization of startup into private stock companies based

upon knowledge-intensive property rights shares of the new science-based startup companies and other rights concerning the management of the company. Limited partnership converges progressively into stock-holding. The personal participation of partners in the startup declines and is substituted by the professional services of managers organized by venture capital companies. The new bundling of equity with managerial competence into knowledge-intensive property rights of science-based startup companies that can be traded can be considered the dominant (product) design that lies at the origin of what will become a new market. In this early phase, venture capital companies co-evolve with the organization of the new science-based startup companies.

The development of venture capital companies and the growth of the syndications as a way to collect funds for new science-based startup companies have played a key role in this phase. Private investors and financial companies that had contributed to the fundraising activities for new companies were eager to elaborate exit strategies for collecting the value of the new firms after their creation and growth, and participate fully in the profits of the 'blockbusters'. The search for 'exit' strategies acts as a powerful dynamic factor at this stage.

Phase III. Trading knowledge-intensive property rights in private markets

Exits took place principally through the sale of knowledge-intensive property rights in the so-called trade sales to individuals or organizations. These are 'private transactions'. During the first half of the 1970s we can observe the growing number of over-the-counter (OTC) initial offerings of knowledge-intensive property rights. Here a critical mass of transactions slowly builds up and triggers, through variation, a more systematic and focused search and experimentation process leading to the emergence of a public market.

Large companies become progressively aware of the important opportunities provided by the new small public companies whose shares are traded over the counter as a source of technological knowledge. Mergers and acquisitions increase as corporations rely more and more systematically upon the takeover of the new science-based companies, after initial public offering (IPO), as a source of technological knowledge that has already been tested and proved to be effective. The acquisition of external knowledge, embodied in the new firms, complements and partly substitutes internal activities conducted *intra muros* within the traditional research laboratories. Specifically, incumbents rely on the new source of external technological knowledge as an intermediary input that can be combined with other internal knowledge sources.

Hence it is clear that the new, dedicated financial markets implement

a new central functionality in the economic system in terms of increased division of labor in the generation of new technological knowledge, and higher levels of specialization in the production of the bits of knowledge that each company is better able to command. From this viewpoint it is also clear that the new markets favor the coordination among different firms specialized in the generation of complementary modules of knowledge that can be exchanged and traded. The new financial markets favor the reorganization of the generation of knowledge, away from high levels of internal vertical integration, towards open innovation architectures (Chesbrough, 2003). The changing organization of the generation of technological knowledge on the new financial markets attracts increasing flows of firms on the demand side. Consequently, the growing demand of the new knowledge-intensive property rights by large incumbents increases the frequency of transactions and hence the thickness of the new markets (Avnimelech and Teubal, 2004, 2006, 2008).

Phase IV. Emergence of a public capital market focused on IPOs

The increasing size of OTC exchanges led the National Association of Dealers to introduce an automatic quoting mechanism to report the prices and quantities of the private transactions. Eventually the mechanisms, better known by an acronym, evolved into a marketplace. NASDAQ became a new market for selling knowledge-intensive property rights to the public at large rather than only to private individuals or organizations. NASDAQ becomes the specialized market for IPOs of the shares of the new science-based startup companies nurtured by venture capital companies and funded with their assistance by groups of financial investors.

Significant adaptations of the institutional environment, for example modifications of the ERISA (Employment Retirement Income Security Act), including the 1979 amendment to the 'prudent man' rule governing pension fund investments in the USA (Gompers and Lerner, 2004, pp. 8, 9) involved liberalization of the constraints on pension fund investment in the stock of new science-based startups.

In parallel, the increasing liberalization of international financial and currency markets had the twin effect of increasing both the demand and the supply in the NASDAQ. On the demand side, a growing number of investment funds entered the NASDAQ to place their capital. On the supply side, the high levels of liquidity, the thickness of transactions and the low levels of volatility, together with the high quality of the professional services available in NASDAQ, attracted the entry of venture capital companies of other countries (in the Israeli case the dynamics is impressive) that eventually represented a large and growing share of the total figure of IPOs of science-based startup companies. An increasing

concentration of exchanges, a key feature of a marketplace, has been taking place at the global level (Bozkaya et al. 2008).

By means of global concentration, sparse, rare and occasional transactions by a myriad of isolated and dispersed agents, scattered around many local markets, were progressively brought into the same physical and institutional context with clear advantages in terms of the number of transactions that occur and hence can be compared and observed.

Here the analysis of Schmookler (1966) on the role of demand in pulling technological innovation applies to explain the final stages of this process of institutional change. Schmookler found strong empirical evidence of a link between capital-good market size (as indicated by gross investment) on the one hand and capital-good improvement inventions (as indicated by patents on capital goods, with a lag) on the other (Schmookler, 1966). Moreover, when it comes to explain the distribution of patents on capital-goods improvement inventions across industries, 'demand' overrides any differences in the 'supply' side of inventions. His analysis suggests that the emergence of new product markets in general and not only capital-goods markets will, through a 'demand' effect, induce improvement inventions in the underlying product and process technology.

Here it is clear that demand for the new knowledge-intensive property rights by investment funds, pension funds and eventually family pulled the final diffusion of NASDAQ with a snow-ball effect in terms of the overall level of transactions. The new levels of mass transactions favored the frequency of IPOs and attracted qualified professional and financial companies specialized in market management. This in turn led to substantial increase in the thickness of the markets, reduction in volatility and eventually global concentration of exchanges.

The concentration of transactions, the thickness of the new markets, and, most important, the ensuing recurrence of transactions on individual stocks have important effects in terms of reduction of volatility. The entry on the demand side of large investment funds, pension funds and ultimately even private investors has the important effect of providing large flows of transactions on the shares of individual companies. The size of the new financial markets makes it possible to better manage uncertainty by means of the distribution of small bets across a variety of actors and of firm-specific equity markets.

In the previous phases, characterized by the preponderance, on the demand side, of large incumbents searching for new science-based companies able to complement their internal knowledge base in order to organize takeovers and subsequent delisting, transactions on individual stocks were sporadic, with high levels of volatility.

This enables NASDAQ to become an efficient mechanism for the

identification of the correct value of knowledge-intensive property rights. This in turn leads it to perform the key function of appreciation of the large share of intangible assets in the value of the new science-based companies (Campart and Pfister, 2007; Bloch, 2008).

The expansion/transformation of NASDAQ is clearly the result of a cumulative process with positive feedback involving a number of processes that make the market more and more attractive to increasingly larger sets of agents (both demand side and supply side). The reasons are similar to some extent to those invoked to explain the dynamics of venture capital or cluster emergence. The new sets of agents that participate in the new markets include specialized agents providing services to investors or companies, for example investment banks, brokers, consultants, and so on; specialized new intermediaries such as venture capital/private equity funds, financial investors and so on. The enhanced volume that their entry induces further reduces transaction costs, which further increases the thickness and frequency of transactions. This also reduces uncertainty to individual investors as well as market volatility, and so on.

Thus, once a new market emerges (e.g. as a result of venture capitalism) and begins to grow, a point may be reached when the private 'benefit' from developing a disruptive technology may become such as to induce 'technology suppliers' like science-based startup companies to undertake disruptive technology development. This in turn enabled exploitation of significant economies of scale and scope, and a momentum for further expansion (dynamic economies or cumulative processes with positive feedback). NASDAQ thereby eventually became the market for transactions on knowledge-intensive property rights in general. NASDAQ in effect became a 'super-market' for products generating income streams for the general public.

The emergence of venture capitalism, defined as the combination of venture capital companies able to screen, fund and assist the growth of new science-based startup companies complemented by a dedicated financial market specialized in the transactions of their property rights, marks important progress in knowledge governance. Venture capitalism has significant advantages with respect to the system architecture prevailing in the second part of the twentieth century, when innovations were mainly selected, developed and commercialized by existing incumbent companies. The new, dedicated financial markets seem better able than the previous knowledge governance mechanisms to appreciate the economic value of technological knowledge, to signal the new directions of technological change, to select the new blueprints and, most important, to provide better incentives respectively to 'inventors', to venture capital firms and to

investors in directing their resources and capabilities towards the generation and use of new technological knowledge.

The new, dedicated financial markets seem able to reduce the limitations of both the hierarchical corporate and the credit-based polyarchic model based upon the banking system. They also seem able to combine the advantages of screening radical innovations of polyarchic decision-making with the advantages stemming from direct participation in the profits of new outperforming science-based startup that are characteristic of the equity provision of finance to innovation, typical of the corporate model.

5. CONCLUSIONS

Venture capitalism can be understood as a new mechanism for the governance of technological knowledge that is the result of a system dynamics where a variety of complementary and localized innovations introduced by heterogeneous agents aligned and converged towards a collective platform. The new mechanism has improved the governance of technological knowledge within economic systems, through the combination of new science-based startups and new, dedicated financial markets specialized in the transactions of knowledge-intensive property rights. Hence it has reshaped the prime mechanism by which the generation of new knowledge can lead to economic growth.

The relationship between technological and institutional change is strong and allows for bidirectional causality. Technological change can be considered the cause of institutional change, as much as institutional change can be considered at the origin of technological change. A large literature has explored the view that the discontinuities brought about by the radical technological breakthrough that took place in the late 1970s with the emergence of the new technological systems based upon information and communication technologies (ICT) can be thought to be at the origin of the progressive demise of the Chandlerian model of innovation centered on large corporations. Venture capitalism has been often portrayed as the consequence of the ICT revolution.

In this work we have articulated the alternative hypothesis. The emergence of venture capitalism based upon new dedicated financial markets specialized in the trading of knowledge-intensive property rights and hence in the systematic appreciation of new science-based startups can be considered a major institutional innovation in the governance of technological knowledge and as such a key factor in hastening the pace of introduction of more radical technological innovations.

The analysis has highlighted the advantages of the new mechanism of knowledge governance based upon venture capital companies able to screen, fund and implement new science-based startup companies and new dedicated financial markets specialized in knowledge-intensive property rights. It has also shown how the emergence of such new markets has been the result of a complex process of system dynamics where a plurality of actors and interests aligned and converged towards a common platform able to integrate and valorize the complementarities between their different profit functions. The emergence of the new financial markets can be considered as a major institutional innovation that is likely to have important effects on the pace of technological change.

Following our line of investigation, we can summarize the main reasons why the process of transformation of radical inventions into new product markets is likely to become more certain, frequent and routinized under venture capitalism: (1) increased numbers of new science-based startup companies with radical inventions; (2) new systemic and generic mechanisms of direct or indirect transformation of such inventions into new product markets; (3) the effect of new markets and more rapid market growth on invention, including radical (both disruptive and non-disruptive) inventions; (4) the possible emergence of unbundled markets for technological improvements.

Venture capitalism creates a cumulative process of innovation-based economic growth. The combination of continued generation of new opportunities and the mechanism for ‘unlocking’ the system from potential, strong past dependence, is evidence that venture capitalism could become a feature of sustainable innovation-based growth.

NOTES

1. Morris Teubal acknowledges the funding and support of ICER (International Center for Economic Research) where he was a Fellow in 2005 and 2008 and the Prime (NoE) Venture Fun Project. Preliminary versions have been presented at the Fifth Triple Helix Conference ‘The capitalization of knowledge: cognitive, economic, social and cultural aspects’ organized in Turin by the Fondazione Rosselli, May 2005 and the following workshops: ‘The emergence of markets and their architecture’, jointly organized by CRIC (University of Manchester) and CEPN-IIDE (University Paris 13) in Paris, May 2006; ‘Instituting the market process: innovation, market architectures and market dynamics’ held at the CRIC of the University of Manchester, December 2006; ‘Search regimes and knowledge based markets’ organized by the CEPN Centre d’Economie de Paris Nord at the MSH Paris Nord, February 2008.
2. So far, this contribution complements and integrates Antonelli and Teubal (2008), which focuses on the emergence of knowledge-intensive property rights.
3. Concerning the nature and function of markets, again following Coase: ‘Markets are institutions that exist to facilitate exchange, that is they exist in order to reduce the

cost of carrying out exchange transactions. In Economic Theory which assumes that transaction costs are non-existent markets have no function to perform' (Coase, 1988, p. 7); and 'when economists do speak about market structure, it has nothing to do with markets as an institution, but refers to such things as the number of firms, product differentiation and the like, the influence of the social institutions that facilitate exchange being completely ignored'.

4. Coase (1988) discusses the elements comprising a market, e.g. the medieval fairs and markets that comprise both physical facilities and legal rules governing the rights and duties of those carrying out transactions. Modern markets will also involve collective organizations, that is technological institutes and mechanisms for the provision of market-specific public goods. They also require a critical mass of buyers and sellers, and institutions assuring standards and quality on the one hand and transparency of transactions and inter-agent information flow on the other.
5. Marshall makes it clear that markets are themselves the product of a dynamic process: 'Originally a market was a public place in a town where provisions and other objects were exposed for sale; but the word has been generalized, so as to mean any body of persons who are in intimate business relations and carry on extensive transactions in any commodity. A great city may contain as many markets as there are important branches of trade, and these markets may or may not be localized. The central point of a market is the public exchange, mart or auction rooms, where the traders agree to meet and transact business. In London the Stock Market, the Corn Market, the Coal Market, the Sugar Market, and many others are distinctly localized; in Manchester the Cotton Market, the Cotton Waste Market, and others. But this distinction of locality is not necessary. The traders may be spread over a whole town, or region of country, and yet make a market, if they are, by means of fairs, meetings, published price lists, the post-office or otherwise, in close communication with each other' (Marshall, 1920, pp. 324–5).
6. Markets can also signal new product or product feature requirements ('unmet needs') within the 'product category' being traded.
7. Our agenda is therefore not only to define and explain the role of markets but also to identify the processes of emergence of new markets. This will include analyzing the conditions under which a set of 'precursor' transactions will not lead to the emergence of a new market. In terms of system dynamics, this could be termed 'left-hand truncation'. Moreover, explaining emergence will require making reference to other variables, that is scale economies in building the market-place (Antonelli and Teubal, 2008).
8. The benefits include savings in transaction costs that should cover the fixed costs of creating and the variable costs of operating a new market (see above).
9. The above framework suggests that failed market emergence could be the result of two general causes. One is failed selection processes resulting from too little search/experimentation and/or inappropriate selection mechanisms due to institutional rigidity. The other is failure to spark or sustain an evolutionary cumulative emergence process (e.g. due to system failures that policy has not addressed). Not all radical inventions, even those leading to innovations and having potential, will automatically lead to new product markets.
10. Students of regional high-tech clusters such as Saxenian (1994) and Fornahl and Menzel (2004) have intuitively recognized the relevance of such dynamics, but not quite elaborated it.

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