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THE ECONOMIC PROPERTIES OF INFORMATION AND KNOWLEDGE: AN INTRODUCTION

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Schumpeter laid down the two cornerstones of the economics of knowledge: the limits of the rewards that innovators can cash and the consequent externalities associated with their introduction. An enquiry into economic properties as an economic good can be regarded as the outcome of a long-time effort of investigation and articulation of the Schumpeterian hypothesis concerning the limited benefits of innovators.

Schumpeter first introduced the view that innovators cannot take advantage of the full stream of economic benefits stemming from the introduction of an innovation. Innovators can appropriate such benefits only for a limited stretch of time: imitation by competitors cannot be impeded or delayed. The entry of new competitors that take advantage of the results of the innovative efforts of other firms cannot be impeded. Consequently, monopolistic market power is needed to induce firms to innovate: “But perfectly free entry into a new field may make it impossible to enter it at all. The introduction of new methods of production and new commodities is hardly conceivable with perfect—and perfectly prompt—competition from the start. And this means that the bulk of what we call economic progress is incompatible with it. As a matter of fact, perfect competition is and always has been temporarily suspended whenever anything new is being introduced—automatically or by measures devised for the purpose—even in otherwise perfectly competitive conditions" (Schumpeter, 1942: 105).

Nelson (1959) can be credited with being the first to try and articulate the implication of the Schumpeterian hypothesis by establishing a direct link between the value of innovations and the amount of resources that a system can allocate in research activities. His point is straightforward: if the private value of the innovation for the inventor is below its social value, the system risks being unable to generate the 'correct amount' of knowledge. In so doing, Nelson inaugurates the simple linear top-down approach that stresses the role of scientific research in generating technological knowledge and the role of scientific knowledge in making the introduction of innovations possible: "The quantity of resources that a society should allocate to basic research is that quantity which maximizes social profit. Under what conditions will private-profit opportunities draw into basic research as great a quantity of resources as socially desirable? Under what conditions will it not? If all sectors of the economy are perfectly competitive, if every business firm can collect from society through the market mechanism the full value of benefits it produces, and if social costs of each business are exclusively attached to the inputs it purchases, then the allocation of resources among alternatives uses generated by profit maximizing will be a socially optimal allocation of resources. But when the marginal value of a 'good' to society exceeds the marginal value of the good to the individual who pays for it, the allocation of resources that maximizes private profits will not be optimal" (Nelson, 1959: 298). In so doing, he draws attention to the limits of the institutional and economic determinants of resources that are invested in the production of knowledge. As Nelson puts it, the limits of knowledge as a private good are at the origin of a divergence between social and private benefit (or cost) and intrinsic externalities.

Arrow (1962a) opens up the fruitful exploration of the characteristics of knowledge as an economic good. In so doing, he first introduced the notion of knowledge appropriability. Arrow makes it clear that the appropriability problem arises if and when knowledge and information coincide: “Information will frequently have an economic value, in the sense that anyone possessing the information can make greater profits than would otherwise be the case. It might be expected that information will be traded in, and of course to a considerable extent this is the case, as is illustrated by the numerous economic institutions for transmission of information, such as newspapers. But in many instances, the problem of an optimal allocation is sharply raised. The cost of transmitting a given body of information is frequently very low. If it were zero, then optimal allocation would obviously call for unlimited distribution of the information without cost. In fact, a given piece of information is by definition an indivisible commodity, and the classical problems of allocation in the presence of indivisibilities appear here. The owner of the information should not extract the economic value which is there, if optimal allocation is to be achieved; but he is a monopolist, to some small extent and will seek to take advantage of this fact” (Arrow, 1962a, pp.615).

An analysis of knowledge as an economic good enables us to unveil the consequences of the overlapping of information and knowledge that leads to another crucial difference with respect to ‘standard’ goods: non-rivalry in use. Knowledge is characterized by non-exclusivity in use. The use of a piece of knowledge by an agent does not prevent its contemporary use by another agent. The Marxian distinction between user value and exchange value, however, helps to specify a further contradiction. Non-rivalry applies to user value, but not to exchange value. Many agents can, indeed, share the contemporary and unlimited use of a piece of knowledge without harming each other. The agent who shares his/her knowledge with others, however, suffers immediate, negative consequences in terms of exchange value. After knowledge has been shared, its market value declines since many sellers can now compete in the market place instead of a single vendor. The price of the knowledge that has been shared declines and the original possessor, the inventor, will experience a loss.

Exploring the possibility to exchange and trade in the market place knowledge as an economic good, Arrow identifies another major limit: “[T]here is a fundamental paradox in the determination of demand for information; its value for the purchaser is not known until he knows the information, but then he has in effect acquired it without cost.”(1962a, p. 615). Arrow can add to the list of limits of knowledge its poor tradability.

The negative consequences of the limited appropriability and tradability of knowledge are enhanced by the huge divergence between its generation and reproduction costs. The cost of the generation of new knowledge may be very high. The cost of its reproduction is always negligible. Limited appropriability and low reproduction costs are at the root of the failure of markets for knowledge for many reasons. First of all, it implies the lack of or the inadequate levels of incentives to invest in the generation of knowledge. Second, it is at the origin of intrinsic information asymmetries that take place between perspective vendors and customers. Customers are reluctant to purchase knowledge without the full discovery of its content and vendors are equally reluctant to provide details about the piece of knowledge since they cannot prevent dissipation of the economic value of their possession after disclosure. As Arrow (1962) notes: in the absence of special legal protection, the owner cannot, however, simply sell information on the open market. Any one purchaser can destroy the monopoly, since he can reproduce the information at little or no cost" (1962, p. 614-615). Information asymmetries lead to non-tradability: the market place is not the appropriate institution for demand and supply of knowledge to interact. Third, the limited opportunities to trade knowledge reduce the opportunity for specialization in the generation of knowledge components and specific knowledge fields. Poor specialization limits in turn the division of labor and the opportunity for learning and concentration of efforts that are at the origin of the Smithian increase in competence. Fourth, the generation of knowledge is characterized by radical uncertainty. It is difficult if not impossible to formulate accurate expectations about the timing and the content of the knowledge generation process. The expected results may be obtained with great delays, while unexpected ones may be achieved raising the problems of their exploitation augmented by their limited tradability (Consoli and Patrucco, 2011).

Finally, limited appropriability and tradability, and radical uncertainty are the cause of the basic reluctance of financial markets to provide firms willing to generate new knowledge, with the necessary funds. Bankers and creditors at large are not ready to provide resources that would be invested in activities that have low chances to generate appropriate pay-backs. Limited knowledge appropriability and tradability are at the origin of substantial credit rationing. Firms can generate new knowledge only if and when have internal financial sources or can access the equity markets. This in turn has major consequences in terms of market asymmetries. Only large incumbents with high levels of profitability are able to fund the generation of new knowledge. Only public companies whose shares are traded in the stock exchange are able to raise the necessary funds by means of equity (Stiglitz, 2000 and 2002).

The analysis of the limits of knowledge as an economic good, provides the cornerstones of the so-called Arrovian postulate according to which market systems are not only unable to allocate the correct amount of resources to the generation of technological knowledge, but also inefficient since they do not provide the necessary set of institutions that can support the tradability, division of labor, specialization and fundability that take place for standard goods. Economic systems that rely exclusively on the market place to organize the generation and dissemination of knowledge are bound to undersupply it.

The market failure has major consequences not only in terms of static inefficiency, but also, and most importantly, of dynamic inefficiency. Because market systems are unable to allocate the correct quantities of resources to the generation of knowledge, their economic growth is at stake. The undersupply of knowledge has negative consequences not only in the present but also and mainly in the future. The limits of the market system in terms of dynamic inefficiency become all the more evident and incisive as soon as knowledge is identified as the main cause of total factor productivity growth (Antonelli, 2005).

The understanding of the limits of markets as the appropriate mechanism for governing the allocation of resources and incentives to generate knowledge paves the way to the exploration and design of other institutions that can efficiently generate and disseminate knowledge. According to Dasgupta and David (1994), within actual economic systems there are alternative modes of organizing the generation of knowledge that build upon specific institutions with alternative sets of incentives, such as priority and reputation in an academic context.

Much subsequent enquiry into the economics of knowledge can be regarded as an attempt to qualify and specify the Arrovian postulate based upon the elaboration of the distinction between information and knowledge. Arrow (1969) draws attention to the limits and constraints of the dissemination and transmission of information: "The transmission of the observation or of the revised probability judgments must take place over channels which have a limited capacity and are therefore costly. Though the language is borrowed from communications theory, the really limited channels are human minds, not telegraphs or printed words. Even for the individual there is a problem of channel capacity. To transform his a priori into *a posteriori* probabilities as the result of observations which have taken time, he must remember his a priori probabilities; but memory is a channel for transmission between points of time and is notoriously limited in capacity and subject to error" (Arrow, 1969, pp. 32).

The dissemination of information takes place at a cost that depends both on its intrinsic characteristics and the capability of communication channels. Since the transmission of information is constrained, recipients bear a cost to acquire the information. The consequences are immediately clear: the imitation of innovations is limited and costly. Hence, the limits of appropriability are less stringent the greater the difference between information and knowledge and the stronger the limitations of information channels.

An appreciation of the crucial role of learning in the generation and exploitation of knowledge marks an important shift in the emerging economics of knowledge. The top-down traditional view that scientific knowledge precedes technological knowledge and its applications for the introduction of innovations, framed by Nelson (1959), is now contrasted with a 'bottom up' approach according to which learning processes are at the origin of new knowledge that is eventually progressively elaborated. The new emphasis on learning processes, learning by doing, learning by using, learning by interacting, paves the way to a new understanding of the difference between information and knowledge. Knowledge acquired by means of learning processes has a strong tacit content that can be articulated and transferred only with intentional efforts (Penrose, 1959; Arrow, 1962b).

The understanding of the crucial role of learning processes in the accumulation of competence and in the generation of technological knowledge has important consequences. As Atkinson and Stiglitz (1969) note learning processes can take place only in the specific techniques practiced by firms. Hence technological knowledge is localized as opposed to generic. Technological knowledge acquired by means of learning processes enables to introduce technological innovations only in the immediate technical surroundings of the original technique that firms had selected and upon which the learning processes were based. Consequently they cannot apply to the full set of techniques of the isoquant. Because of the localized character of technological knowledge, technological change can only take place along the isocline that relates the technique in place at the time of the learning process and the origin. Major efforts are necessary to convert localized technological knowledge into generic technological knowledge. Top down science based knowledge generation processes are necessary to complement the bottom-up generation processes based upon learning. The distinction between localized and generic knowledge has major consequences on the debate (Antonelli, 1995).

Further progress has been made in the distinction between information and knowledge with the debate on tacit knowledge. The distinction between tacit and explicit or codified knowledge elaborated by Michael Polanyi becomes relevant in the economics of knowledge as the basic tool for outlining the distinction between information and knowledge. According to Polanyi (1958 and 1966), knowledge has an intrinsic, irreducible tacit content that can only be transferred to third parties with substantial and intentional efforts. People, and organizations, know more that they are aware of: a significant component of personal knowledge is possessed without full control. The transfer of tacit knowledge can take place, to some extent, only by means of repeated interactions between knowledge owners and knowledge recipients. Tacit knowledge is acquired by means of learning processes and can be articulated and codified. The codification process requires dedicated, intentional efforts, new technological knowledge is mainly tacit at the origin, and its explicit content increases over time, as a consequence of repeated codification efforts. In order to learn the explicit knowledge generated and codified by third parties, perspective recipients must carry on dedicated uncoding and recoding activities (Ancori, Bureth, Cohendet, 2000).

Saviotti (1998) establishes a direct link between the degree of codification and the degree of appropriability and argues that the extent to which knowledge can be codified increases with its maturity whereas appropriability declines. Indeed, appropriability depends on the degree of codification that becomes easier with the age of the knowledge, the fraction of the population of agents knowing the code that increases with the codification itself, and the distribution of knowledge among the agents who are potential users of the knowledge.

Von Hippel (1994) introduces the notion of knowledge as sticky information: “As an aid to exploring patterns in the locus of innovation-related problem solving as a function of information transfer costs, we coin the term "sticky" information. We define the stickiness of a given unit of information in a given instance as the incremental expenditure required to transfer that unit of information to a specified locus in a form usable by a given information seeker. When this cost is low, information stickiness is low; when it is high, stickiness is high. Note that in our definition, information stickiness involves not only attributes of the information itself, but attributes of and choices made by information seekers and information providers. For example, if a particular information seeker is inefficient or less able in acquiring information unit x (e.g., because of a lack of certain tools or complementary information), or if a particular information provider decides to charge for access to unit x, the stickiness of unit x will be higher than it might be under other conditions” (Von Hippel, 1994: pp.431; Von Hippel, 1998).

Another characteristic of knowledge concerns its scope of application or fungibility. Inventions may have a limited scope of application when they feed the introduction of innovations into a limited range of products and process. Other inventions, identified as general purpose technologies, occasionally have a wide scope of application that can support the introduction of a wide set of innovations affecting a large part of an economic system (Bresnahan and Trajtenberg, 1996). General purpose technologies are often the result of the Schumpeterian convergence of an array of complementary innovations that concentrate in time as gales and form a new technological system (Schumpeter, 1939; Lipsey, Carlaw, Bekhar, 2005).

The indivisibility of knowledge emerges as one of its key characteristics after much investigation devoted to non-appropriability and its consequences. The non-divisibility of knowledge consists of its diachronic cumulability and synchronic complementarity. New knowledge can be produced only by standing on the shoulders of giants. There are high levels of complementarity between the research activities of agents at the same time. Various innovations and output of research activities performed in different organizations must be integrated and used at the same time and cannot go below a minimum level without putting the final innovative outcome at risk.

As Caballero and Jaffe put it: “In the process of creating new goods, inventors rely and build on the insights embodied in previous ideas; they achieve their success at least partly by "standing upon the shoulders of giants." The public stock of knowledge that accumulates from the spillovers of previous inventions is thus a fundamental input in the technology to generate new ideas. This is clearly reflected in Schmookler's (1966) description of the inventor's problem:. . . the joint determinants of inventions are (a) the wants which inventions satisfy and (b) the intellectual ingredients of which they are made. The inventor's problem arises in a world of work and play, rest and action, frustration and satisfaction, health and sickness, and so on. .. [i]n order to analyze the problem, to imagine possible solutions to it, to estimate their relative cost and difficulty, and to reduce one or more to practice, the inventor must use the science and technology bequeathed by the past . . .” (Caballero and Jaffe, 1993, pp. 16).

The use of knowledge is characterized by its non-exhaustibility. The repeated use of knowledge does not produce the standard “wear and tear” effects that characterize any tangible good. Knowledge non-exhaustibility has important consequences on at least two levels. First, the very same piece of knowledge can be used for the production of unlimited quantities of goods. The costs of the original generation of that piece of knowledge can be spread on unlimited quantities of goods. Actually the larger is the quantity of goods that can be produced by means of that piece of knowledge and the lower are the average unit costs. Second, the very same piece of knowledge can be used repeatedly for the generation of new pieces of knowledge. The costs of the original piece of knowledge are sunk and the costs of the additional pieces of knowledge that use it as an input can be regarded as "incremental costs". For these reasons technological knowledge shares with basic infrastructures and all indispensable inputs characterized by historic duration the basic characteristics of an essential facility (Antonelli, 2007).

For quite a long period of time, knowledge has been regarded and analyzed as a homogeneous bundle of items. The increasing variety of its attributes and the distinctions that have been identified between types of knowledge calls for an effort to distinguish between knowledge(s) and identify its respective characteristics. The notions of knowledge base and knowledge modularity are the result of this line of investigation

The case of digital information and communication technologies (ICTs) display clear tension between indivisibility and (partial) appropriability. ICTs are the result of strong complementarities between innovations and technologies developed in different technological fields, thus between different knowledge bases. Yet, these knowledge bases are increasingly appropriable either because tacit to a great extent or because they are covered by patents and licenses. Therefore, knowledge in this case is indivisible but also partially appropriable and therefore modular (Langlois, 2002).

Developing the intuition of Edith Penrose (1959) according to whom the performances of firms depend not only on the quantity of knowledge but also on the composition of their competences, Nesta and Saviotti (2005) study the portfolio of the knowledge base of firms and focus on its diversity and coherence. This analysis of the portfolio of firm patents reveals that each firm is active in a variety of scientific fields with varying levels of coherence, defined in terms of the relatedness between the individual items of scientific and technological knowledge. According to Nesta and Saviotti (2005), the more related the components of knowledge are, the higher the coherence of the firm's knowledge base and the higher the performances of firms in terms of innovative output, growth, and profitability. The positive effects of related variety, tested according to the variety of products and activities, also apply to the variety of knowledge(s).

The understanding of the variety of knowledge(s), their distribution across agents and the importance of the composition of the different baskets of knowledge(s) paves the way to appreciating the notions of knowledge complexity and modularity (Simon 1962 and 2002). Knowledge is now viewed as a system of specific items that have multiple interactions and interdependence in terms of coherence, complementarity and cumulability (Sanchez and Mahoney, 1996).

Knowledge can now be represented as a map of modules characterized by varying levels of coherence, complementarity and cumulability. The intensity of links between knowledge items helps to identify the modules that each one belongs to, the internal structure of each module, the centrality/marginality of each knowledge item, and the relative distance between modules. Network analysis is successfully applied to investigate the changing distribution of the links and the continual re-organization of the internal structure of the knowledge modules and architecture of the whole system. Citations and co-occurences in the authorship of scientific essays and patents provide the empirical evidence on which the investigations are based (Antonelli, Krafft, Quatraro, 2010; Krafft, Quatraro, Saviotti, 2011).

The appreciation of the heterogeneity of knowledge adds a new layer to the understanding of the composition and role of the system: next to the variety of firms, regions and industries, the composition of the knowledge bases - in terms of specialization, diversification, complementarity, interoperability and interdependence- from which firms can draw the necessary external knowledge, plays an important role.

An investigation into the properties of knowledge can be represented as a process of discovery and understanding of the complexity of knowledge and articulation of its composition. Discovery of the complexity of knowledge enables us to abandon the original simplest linear model (SLIM) where as David (1993) notes: "(the) elementary and familiar construct depicts technological change and productivity growth as the end results of a unidirectional causal sequence, often graphically represented by a series of boxes, each connected to the next by a single arrow pointing from left to right. The system flow-chart tells us that (1) fundamental science yields discoveries, which lead to (2) experimental findings of applied science, which lead to (3) acts of invention, which provide the stimuli and basis for (4) entrepreneurial acts of innovation (commercial introduction of novel products and production methods), which incite (5) imitation and so bring about (6) diffusion of the new technology into general use. From diffusion will flow changes in productivity and welfare improvements but also quite possibly profound alterations in market structure and untoward effects such as the displacement of workers, the downward valuation of assets rendered economically obsolescent, and the demise of firms that fail to adapt to the competitive pressures unleashed by more efficient methods and better-quality products" (p.216).

As David (1993) points out, the overcoming of the simple linear model is based on three "glaring deficiencies. The first problem, which has just been reviewed, is the inadequacy at an epistemological level of the account it provides of the evolution of the stocks of scientific and technological knowledge. The second is the depiction of science as neatly separated into fundamental and applied compartments, with the activities carried on in the first compartment being exogenous to the economy and therefore appearing in the role of the driver of the entire sequence of activities and events. The determinants of induced invention and the institutional conditions affecting market-oriented investments in research and development (R&D) thus receive no explicit notice. Instead of extending an influence backward into the search for scientific principles that will help guide a profit-motivated research in quest of pre-specified new products or production techniques, would-be inventors in the world of SLIM await their cues from the realm of autonomous science. The third major distortion of reality is that changes in the technological opportunity set available to producers are conceptualized as resulting from discrete advances or research breakthroughs. There is a great deal of evidence, however, that most long-run increases in technical efficiency and declines in the price-performance ratio of products in an industry have been the result of the cumulation of a myriad of small improvements. These incremental modifications are usually based on experience gained in actual production operations and in the repeated interactions between the users and the manufacturers and vendors of complex products. In short, endogenous experience-based learning, which is predicated on having gotten beyond the innovation stage, is an important source of the technical developments that SLIM would ascribe to an anterior stage of invention" (p.217).

The understanding that knowledge is at the same time the output of a dedicated activity and an indispensable input to other downstream activities that range from the production of other goods to the generation of new technological knowledge can be regarded as a main achievement in the new approach to knowledge as an emergent system property (Antonelli, 2008 and 2011).

The simple linear method is now substituted by the understanding of knowledge as a complex process divided into a variety of components that form subsystems that interact and complement each other feeding occasional feedback loops in a context heavily characterized by the institutional architecture of relations between agents within the economic system (Simon, 1962 and 2002).

The analysis on the dual role of knowledge as both an input and an output enable to identify one more aspect of knowledge heterogeneity. Knowledge bundles are heterogeneous from many different viewpoints. Not only with respect to the different levels of appropriability, cumulability, non-exhaustibility, fungibility (…) of the different knowledge(s), but also with respect to its actual use. The investigation on the heterogeneity of technological knowledge has brought to the identification of the distinction between knowledge as an intermediary good and knowledge as a final good. The Arrovian postulate assumes implicitly that knowledge is an intermediary input. The limits of knowledge as an economic good and the consequent market failure and the risks of undersupply are all the more harmful when knowledge is an input for the generation of new knowledge and for the production of all the other goods. When knowledge can be regarded as a final good that enters the utility rather than the production function only static efficiency is at stake. When, instead, knowledge can be regarded as an intermediary and capital good not only the static efficiency but also the dynamic efficiency of the system are at risk. The negative consequences of the limits of knowledge as an economic good may be considered less relevant when it is a final good and much more important when it is an intermediary and a capital good. In this case not only the present efficiency of the system is undermined, but also its capability to growth in time (Antonelli and Fassio, 2014).

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