

KNOWLEDGE AND THE EVOLVING ECONOMY

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Abstract

This paper addresses the problem of knowledge and the far-reaching implications it bears upon innovation and the functioning of economic systems. It develops a stylised analysis of the micro-dynamics of knowledge generation, exchange and absorption. It discusses the properties of knowledge accumulation as a complex process: adaptive, path-dependent, context-dependent, open-ended and creative in the sense that it always entails the potential to endogenously generate radical novelty, in line with theory and evidence from the economics of innovation, but fundamentally at odds with a number of important tenets of equilibrium economics.

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1. Introduction

The role of intangible assets in fostering and sustaining processes of economic growth is now received wisdom in both the economic and policy debates. No shortage of ways exist to label modern competitive markets ('Knowledge Capitalism', 'Intellectual Capitalism', 'Knowledge Society', 'Knowledge Economy', 'Learning Economy'...). Scholars of the economics of technical change have stressed more than others that the search for new knowledge is intentional, costly, and yet uncertain. As a consequence, it cannot suffice to say that learning occurs automatically with the passing of time, to argue that time ought to be used as a proxy for variables that we cannot easily observe and measure, and therefore they cannot be objects of scientific investigation, or to assume 'states' of knowledge to be treated as stocks in modelling exercises where agents are rational, time is reversible and history does not exist.

In order to answer a number of questions on economic growth an analysis of *processes* of knowledge generation is arguably more important than an analysis of *states* of knowledge. Processes are more important because, however fundamental the initial and end conditions might be, the generation of new economically valuable knowledge leads to the generation of a new division of labour, which in turn redefines not only the extension of the market but also a new division of knowledge, in a typically out-of-equilibrium process where history matters and future 'states' cannot be anticipated.

This essay is concerned with the economic problem of knowledge and the implications it bears upon innovation and the functioning of economic systems. It builds on a framework of understanding where knowledge generation processes are embedded in social networks. Recognition of the interpersonal nature of knowledge would not have surprised (at least) Smith, Marshall or Hayek. Nor would most anthropologists or sociologists. Nevertheless, this notion has somewhat been lost in the mainstream world of undifferentiated atomised agents, who are effectively asocial in that they are posited to act in a vacuum deprived of social structure.¹ On the contrary, the value of social interdependences for learning has increasingly been appreciated in streams of research emphasising how scientific, technological and business knowledge originates from the interdependence of economic agents and is shaped by their interactions in network structures of varying sizes and degrees of homogeneity and cohesion (see, among others, Granovetter, 1985; Storper, 1993; Maskell and Malmeberg, 1999; Powell and Grodal, 2005; Mina et al., 2008).

The production of knowledge is not only purposefully organised in specific institutions (education and science and technology systems, which include of course both universities and firms' R&D), but also self-organised through the interactions of agents in social communities distributed within and across organisations. In essence, knowledge develops with social interaction and the

form of interaction that is most relevant for the creation and transmission of knowledge is a *communication act*. The vast literatures on industrial clusters and on communities of practice substantiate the point with strong empirical evidence. It is then from a stylised analysis of a communication act that we start this investigation into the dynamics of social learning and its fundamental implications in the functioning and development over time of economic systems.

2. Non-Neoclassical Approaches to Knowledge: Contributions and Open Questions

Contributions on the problem of knowledge framed in the neo-classical tradition of Arrowian mould make no distinction between knowledge and information.² Critics of such approach argue, instead, that knowledge significantly differs from information – and the two concepts should not be used as synonyms – because while information shows properties of a public good, knowledge does not (Foray, 2004; Antonelli, 2008; Dosi and Grazzi, 2010). Not all knowledge can be transferred at zero costs and/or subjected to non-divisible, non-excludable, and non-rival use. Michel Polanyi (1962), a much-cited reference on this problem, identified a few attributes of knowledge and accordingly pointed at the existence of different *types* of knowledge. Knowledge can be personal or tacit as opposed to public or codified, the first being difficult to express, therefore obtainable only through imitation and experience, and the second, conversely, easy to express and transfer.

Nelson and Winter (1982) emphasised the tacit components of firms' capabilities in their fundamental contribution to evolutionary theory. Since then, one of the problems that have captured special attention among economists concerned with issues of innovation and change is that of the codification of knowledge.³ From a theoretical viewpoint, taking Nelson and Winter's observation that tacitness is a matter of degree, Cowan and Foray (1997) and Cowan, David and Foray (2000), among others, investigate the incentives, conditions and procedures through which tacit knowledge can be turned into explicit knowledge.⁴ Empirical research has also been conducted (see, for example, the special issue of Research Policy n. 30(9) (2001), and results show that codification processes are increasingly important, and yet costly, activities of firms'.

In their critique of Cowan, David and Foray (2000), Johnson et al. (2002) argue that an approach heavily focused on the process of codification would incur a number of difficulties, which we re-elaborate as follow. Firstly, there is a risk of paying too little attention to the process of information exchange – which is instead fundamental because it is then that information acquires economic meaning and value. Secondly, processes of interactive and mutual learning risk

be vastly underestimated or wrongly assumed perfectible if only they could be codified (intended as written down). Thirdly, the codification argument seems to tell only half of the story: once information has been produced and transmitted, in fact, what happens on the other ‘side of the wire’?

Introduction of the concept of ‘absorptive capacity’ (Cohen and Levinthal, 1989, 1990) substantially enriches the debate by shifting the focus from the producers of information flows to the recipients, that is to say from the origin to the end of the process.⁵ This line of enquiry appreciates the presence of elements of interdependence and interaction in learning processes but analyses of its microdynamics and clear-cut definitions of what it is that is being absorbed are often missing.⁶ Also, and in spite of Cohen and Levinthal’s insistence on the fact that firms must actively engage in communication and information-gathering activities in order to ‘absorb’ knowledge from the external environment, there is often a vein of passivity in the way the notion of ‘absorption’ is used in the literature, which seems to imply that information is ‘caught from the air’ by individuals without any creative effort.⁷

Much attention has been devoted to the interactive nature of learning by Lundvall (1992), Von Hippel (1995), Nonaka and Takeuchi (1995), Antonelli (1999a, 1999b) and Antonelli and Quéré (2003), who point at the role played by socialisation practices especially in the transmission of tacit knowledge. The main argument is that agents cannot absorb knowledge embodied in other agents, and which is not ‘externalised’ through codification processes, but by being co-located and co-operating in the same environment. Nonaka and Toyama (2002) aptly define the firm as a ‘dialectical being’ where knowledge is created through social interaction. On this account, communication routines and channels are identified as variables of paramount importance.

3. Knowledge, Information and the Intermediate Role of Messages

For the purposes of this paper, knowledge is a complex structure⁸ of interrelated propositions, norms and beliefs. Learning is instead the path-dependent process through which new knowledge is developed. The form of interaction through which knowledge is ex-changed is communication (Rogers, 1983), which in turn is a process by which social actors use their knowledge to produce *messages*.⁹ The role of messages as carriers of knowledge was explicitly treated by Boulding in 1953 and by Machlup some thirty years later (1980). Their point is taken and elaborated upon by David and Foray (1995) and Cowan and Foray (1997). David and Foray (1995) define codification as ‘the reduction and conversion of knowledge into messages that can then be processed as information’ (p. 596). Cowan and Foray (1997) also identify three steps in the codification process: 1) the creation of a model, which entails modelling tacit

knowledge in such a way that the latter can be turned into information; 2) the creation of a language, on which codes of expression are based; 3) the creation of messages, which contain pre-existing knowledge and, as already mentioned, can be processed as information.

In order to be exchanged, a message needs some kind of material entity that makes it 'perceivable'. Information can be thought of as such material and perceivable structure.¹⁰ Messages become embodied into information by means of structured physical alterations performed by individuals on selected elements of the environment, such as airwaves, writing surfaces or electric impulses, according to the nature of the code. If individuals did not alter any perceivable physical structures, no communication could take place, since messages could not possibly be conveyed to and perceived by other individuals. Information, therefore, is a physical representation of sub-sets of knowledge external to the mind of individuals. Messages have to do with the content of communication acts and are the fundamental input and output of knowledge creation processes. Information, instead, has to do with the physical existence and persistence of messages in the perceivable world. While the means by which messages come into being are the *codes* of the communication act, the means by which information is produced, transferred and received are the *media* or *channels* of the relevant communication act (Figure 1).

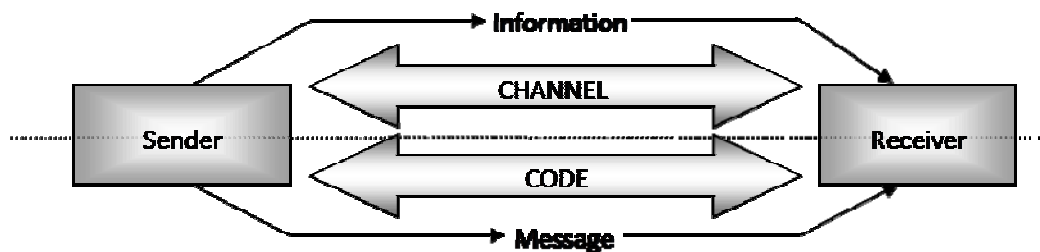


Figure 1

Channels may or may not consist of artefacts socially and technologically shaped. Face-to-face communication, for example, can take place without the aid of any specific device external to the body.¹¹ The observation that face-to-face communications entail codification processes can help to highlight a recurrent misunderstanding on the nature of codified knowledge. 'Codified' is often used to define written long-lasting messages (see, for example, Cowan and Foray, 1997). From a semiological viewpoint, however, the enunciation of a sentence is no less a codification process than the production of a letter. What really distinguishes the two cases is the nature of the medium used, which is highly volatile for the act of speaking, and relatively permanent for the act of writing, and the related differences in the notation (phonic vs. graphic) of the same code (a natural language). It is obvious that codes of different kinds, based on different properties of human senses, are suitable for different

media/channels which can be used to communicate according to the nature of the relevant knowledge that is to be expressed (and, consequently, of the information that is to be exchanged).

It is also important to emphasise that when ‘codified’ is intended as ‘disembodied’ and ‘objectified’ knowledge, the problem that is really at stake is not the codification of knowledge but its *commodification*.¹² The economic relevance of the process of commodification clearly is the possibility of trading knowledge independently of the physical presence of agents, so that markets for knowledge can be conceptualised once appropriability conditions are institutionally granted in the form of patents, trademarks or copyright and agents are able to protect and eventually exchange the produce of their investments in research and development.¹³

There are different forms of, as well as different purposes for, codification and communication. The main trade-off is identified in Nelson and Winter’s (1982) discussion of the notion of tacit knowledge and expressed in these terms: when the problem of codification is connected with the problem of reproducing and transmitting routines within organisations, or across organisation for co-operative purposes, the production of documents and blueprints is not unrelated to the process of personal communications that may either complement it or function as a substitute for it, depending on their relative costs and performances.

The possibility of preserving messages and eventually transferring them in time and space is influenced by the nature, performance and cost of available technologies, by the material form in which the message is produced, by the specific norms of exchange that regulate alternative ways of communicating and by the purpose of the agents. The main costs of communication are given by the opportunity costs of acquiring the knowledge that is necessary to produce or understand a message, including knowledge of the code and knowledge of the context, and the opportunity costs of establishing the link for the interaction if the goal of the relevant agents cannot be reached but through targeted and repeated interaction among specific individuals, as Lundvall (2002) and Johnson et al. (2002) most clearly suggest when they mention, among other examples, the complex process of training PhD students.¹⁴ In addition, there would be the cost of the channels, terminals and storing devices, or the cost of their rent if these were not irreversibly acquired by the agents. Finally, the opportunity costs of codifying and de-codifying messages and those of producing and receiving information.

The production of messages differs from the production of information in that a message can be fully structured in the mind of the sender before it is actually turned into perceivable forms. The potential for the production of messages can only be internalised by acquiring the labour services of agents while

information can be appropriated through the enforcement of property rights. While the opportunity costs of generating a message can be substantial, the perceivable form in which the message can be embodied, that is information, can in principle be replicated at approximately zero costs (which is, of course, the core of Arrow's paradox of the sub-optimal production of knowledge).

4. Codification, De-codification and the 'Exchange' of Knowledge

Collins (1985) argues, and Ancori et al. (2000) recall, that strictly speaking knowledge cannot be transferred. In a narrow sense, knowledge is physically embedded in the brains of the individuals and cannot be 'exchanged'. At best, it can be *approximately* replicated through effective – but not necessarily efficient – communication acts. Figure 2 illustrates some simple analytics of how this happens between two agents, a sender and a receiver.

Firstly, the sender conceptualises an idea through an act of *insight* and codifies a message. Secondly, she produces signals (emission), which can be regarded as 'information units', or 'quanta of novelty' in Shannon and Weaver's (1949) terms, so that the message can be a) transported to and b) perceived by the receiver. As already said, such 'transformation' is an alteration of some perceivable elements of a common environment in which both the sender and the receiver operate. On the receiver's side, signals are perceived and retained (reception). Then, they are a) decoded b) interpreted and c) internalised by the receiver. The expected output of the process is a variation in the receiver's knowledge.

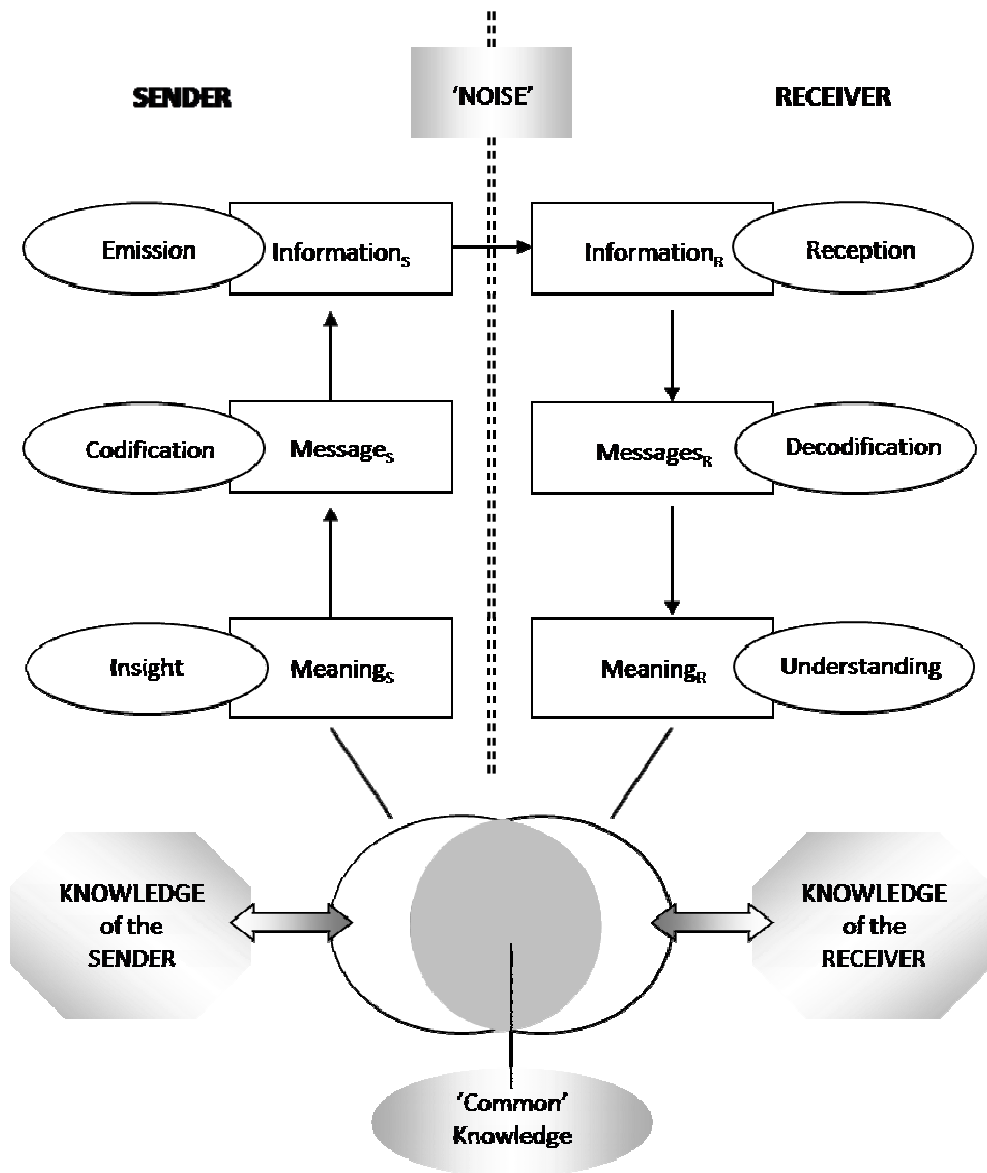


Figure 2

Although mentioned by a number of information economists, the importance of receiver's side of the process, as already noticed, is often overlooked or underestimated. One likely explanation is that processes of de-codification, interpretation and understanding cannot be easily observed and/or measured. However, fundamental properties of the process of knowledge generation depend precisely on the mechanisms through which data gathered by the individuals' senses are absorbed, integrated and used.

To begin with, if a message has been codified but is not or cannot be de-codified, then it has no use outside the mind of the producer. The natural consequence is that if the message has no use, then it has no actual value. Secondly, to become of some use, the message must be interpreted and understood. Interpretation is the process through which meaning is extracted from the message and put in relation with existing messages already in the mind

of the receiver. When a message is ‘interpreted’, its meaning becomes integrated into the structure of the receiver’s knowledge. This equates to say that new messages are introduced into a pre-existing ‘correlational structure’ and that knowledge grows when *new connections* are established between parts of a system in motion (Loasby, 1999, 2001a, 2001b; Potts, 2001).

The implications of this notion are manifold. The first obvious one is that the receiver, apart from having access to the relevant information, must know the code in which the message has been produced and at the same time have pre-existing models of reference for the interpretation of the message (Saviotti, 1998; Cowan et al., 2000), otherwise the meaning conveyed in the exchange is lost because it cannot be understood.¹⁵ The second is that there can be little passivity in the ‘absorption’ of messages because the whole process requires motivation, attention and intellectual effort (in brief, human purpose) and because even if it takes place unconsciously, it still triggers fundamentally creative and idiosyncratic mechanisms, as Ziman (2000) points out.

The third is that learning has cumulative nature and that the accumulation process is localised and non-random (Dosi, 1982; David, 1994; Freeman, 1995, Metcalfe, 1998, Antonelli, 1995, 1999b; Dosi and Grazzi, 2010) in a very specific sense: that interpretation of new components of the broader structure depends on the nature and interpretation of previously acquired messages and that the sequence of connections in time also matters (Rizzello, 1999). The same message is interpreted differently according to the specific point in time at which it is acquired, because as time goes by, knowledge changes, which means that the message is connected to different messages at different points in time even by the same individual.¹⁶

5. Shared Knowledge, Correlated Understanding and Novelty

Knowledge is input and output of a communication act and is object of message-creation as well as message-absorption processes. While the formulation of a message starts with an insight, develops through codification and ends with the production of a signal, the absorptive process starts with the reception of the signal, proceeds to the ‘extraction’ of the message via decodification and ends when its meaning is understood. It is fundamental to notice that even though changes in knowledge through communication require at least two agents, knowledge, as argued by Loasby (1999, 2001b) and Metcalfe (2001; 2010), strongly maintains its individual nature because meaning can only emerge in the minds of individuals.

Strictly speaking, there can be no knowledge outside the minds of individuals, but only representations of knowledge. ‘Public knowledge’ is in fact information that is not or cannot be appropriated given the negligible costs of reproduction and relative ease of propagation. Similarly, the notion of ‘common

knowledge' refers to information that has been internalised by a number of agents (Ziman, 2000) who belong to the same (more or less permanent) social community. It must be noted, however, that the fact that agents appear to respond in the same way to a particular stimulus, does not necessarily imply that the agents know the same things, but simply that they have learnt to give that specific response when faced with that particular stimulus. The connotations of their answers, that is their structure of active connections, and the process by which they reach such answers may in fact differ substantially.

Metcalf and Ramlogan (2001) focus on the dynamics of interpretation when they elaborate on the notion of 'correlated understanding' and shift attention from the substantive content of a message to the framework for understanding shared between agents. This is an important argument because it emphasises a fundamental condition for social interaction without binding the agent to know anything in common, which they cannot do but metaphorically. And yet agents can relate to a message in a sufficiently similar and consistent way as to make their actions compatible. Runde et al. (2009) explore this same principle in some depth in their discussion of the process through which technological objects are attributed 'identities' by means of collective assignments of functions.

The notions of common knowledge and correlated understanding can be conceptualised as statistical constructs 'bridging' the mindsets of the sender and of the receiver.¹⁷ From this viewpoint, they are proportions of internalised meaning shared between the agents with respect to a message or a set of messages. 'Perfect common understanding' would correspond to what in standard theory of information would be the outcome of communication processes in the absence of noise. In other words, 'common knowledge' results from the intersection of 1) the set of semantic components of the message sent and 2) the set of semantic components of the message received. 'Common knowledge' is perfect when noise tends to zero and the two sets coincide. However, virtually all communication acts performed by individuals involve varying non-zero degrees of ambiguity.¹⁸

Two types of 'noise' can be identified. First of all, there is noise at the information level, due to perturbations in transmission. In this case, if iterative correction mechanisms are enforced, a replica or quasi-replica of the original information can be retrieved by the receiver through the progressive elimination of noise. In loose terms, this is the principle underlying Wiener's (1948) process of 'negative feedback': whenever a system is diverted from an expected equilibrium by a disturbance, the difference between the actual state and the desired state is 'fed back' into the system as many times as it is deemed useful to suppress it. If knowledge could be reduced to information, this error-correction mechanism would be enough to guarantee that messages would not change throughout a process of diffusion. Optimality or near-optimality

conditions could be identified and the outcome of a communication process could be said to be perfect at the attainment of a state of equilibrium between the message sent and the message received.

But if knowledge is distinct from information there is a second form of noise that is worth pointing at. This is in some respect ‘substantial’, non-phenomenological noise. It is generated in relation to a message at a semantic level by differences in the knowledge structures of communicating agents. Since these differ, as their past experiences are different (Lachmann, 1978), then the event that the agents interpret and understand the same message in exactly the same way is unlikely, since the relevant connections would be different. Ambiguity emerges as an unavoidable property of human interactions.

One crucial implication of this is that every time messages are exchanged, margins of semantic ‘error’ can be introduced into the system, with the consequence that the *variety* of the system is increased. Novelty is in fact generated not only because of the creativity of actors in producing messages, but also because of their idiosyncratic interpretation of messages. It follows that understanding can conduce to very high levels of divergence and novelty when the knowledge structures of the agents, although correlated, are sufficiently different.¹⁹

A second implication is that while information can then be said to diffuse, the same cannot apply to knowledge. Naturally, if agents are neoclassical ‘representative’ agents there really is no problem, because knowledge is perfectly reducible to information. If, in fact, agents do not differ from each other, they would all interpret the same message in the same way and quite interestingly, at equilibrium, the message would have to arrive as ‘manna from heaven’ since there could be nothing that agents may want to exchange given that they already know exactly the same things. In this respect, equilibrium would be a motionless world of silence.

But if agents are heterogeneous – as they necessarily are because they differ in their experience even if they were born identical – and if they are not isolated in a social vacuum – which would enormously reduce their chances of survival – it follows that messages not only are endogenously generated and continuously circulated within the system, but also that no message can spread without being continuously transformed through the very process of exchange. This is the reason why information can be treated as mobile, but knowledge cannot and while information can diffuse, knowledge must develop in the minds of individuals through the contextual emergence of meaning.

Given that there is a varying probability that agents interpret differently the very same message at any point in time (not to mention the probability that the same agent interpret differently the same message at different points in time), a trade-off is immediately configured between co-ordination and variety-creation. The

closer the knowledge structures, the higher the probability that the agents react similarly to a message/stimulus, in the sense that they understand similar things and devise highly compatible response strategies. Co-ordination is therefore strongly favoured. The wider the discrepancies between the knowledge structures, instead, the higher the probability that agents develop diverging interpretations of the same message, hence the higher the innovative potential of the interaction. Different risks are also associated with the two cases: in the first, the risk of total homogeneity, hence sterility; in the second, the risk of radical misunderstandings, hence the impossibility of compatible expectations, which is a pre-requisite for co-ordinated action.

Noteboom (1999) interprets the problem in terms of ‘cognitive distance’ between individuals and argues that the closer the knowledge of the agents the easier – that is cheaper from a transaction cost viewpoint – their mutual understanding. The interaction between ‘close’ agents, however, will yield less innovative outcomes because the new connections, or Schumpeterian new combinations of knowledge, emerging from their co-operative action will be limited to a narrower scope.²⁰ This trade-off can be empirically observed in evaluating the outcomes of R&D partnerships, joint ventures and mergers as well as in the systematic scrutiny of the sources of industrial innovation (see Utterback (1994) for producers and Von Hippel (1988) for users as innovators).²¹

Granovetter (1973) followed a similar line of argument when stressing the potential for novelty as ‘the strength of weak ties’. The role of weakly connected agents is fundamental, for example in the diffusion of innovations, because they are likely to have a superior number of connections, thus favouring the propagation of novelty throughout the system. Granovetter raised a very important point not least because he emphasised precisely the role of marginal agents in the evolution of social coalitions. This leads us to consider that a crucial condition for progress, including of course scientific progress, is the potential of disagreement, which is nothing but another way of stressing the necessity of variety (Metcalf et al., 2005). If everybody agrees, there are in fact no sources of novelty capable of fuelling improvements. Nonaka and Toyama (2002: 995) are then very right when they argue that knowledge is ‘dynamically created out of contradictions’, and later on (p. 1000-1003) that the firm’s main capability must be that of ‘synthesising contradictions’ through the organisation of interactions among its members.

In discussing the production of scientific knowledge, Ziman (1994: 19) stresses the potential for novelty stemming from the association of the most diverse ideas and notices that ‘...The linking of apparently unrelated pieces of information, technique or theory has always been one of the most creative processes within science’.²² He then observes (p. 19) that ‘...The list of unforeseen connections is endless’ and, most interestingly, reminds us that the

structure of knowledge must be *fractal*, and not linear, in analogy with the micro-structure of neural networks. But in considering the growing importance of interdisciplinarity in team research, Ziman also remarks (ibid: 108) that ‘...collaboration is often hampered by lack of clear understanding of the common purpose of the work’, which can be configured as a fundamental problem not only in the development of scientific communities, but in that of any form of community.

The problem of social co-ordination emerges in a range of scenarios between the knowledge sets of agents who are not totally different – otherwise they could not relate to each other at all (cf. the language/code problem) – but at the same time not identical, since if they were, given appropriate incentives, their actions would be instantaneously compatible. The neoclassical representative agent clearly conforms to this second case, where the very notion of ‘representativeness’ implies as a necessary condition that knowledge be treated as information, so that signals can always have the same meaning and bring about the same consequences.

Hayek (1937; 1952) was acutely aware of the paramount importance of understanding deep down in the fundamental mechanisms of the economy and envisaged most clearly the consequences upon economic theory of the conjecture that agents can produce a variety of interpretations from the same signal. As Desai (1994) explains, for Hayek this became a major source of dissatisfaction with the notion of equilibrium, and greatly contributed to his estrangement from the Walrasian framework during the 1930s. Equilibrium required the perfect interpersonal (and inter-temporal) compatibility not only of preferences, but also of expectations. How can this be, if there is no uniform and unchanging interpretation of the same ‘objective facts’ and individuals are not endowed with perfect foresight? The problem is further exacerbated when considering that expectations do not simply concern prices (the information set), but also the ‘plans’ for action of individuals (the opportunity set). The theoretical consequences are far-reaching and include a fundamental shift from an equilibrium framework to one where co-ordination is not a given and where the emergence of order in economic systems becomes a central focus of investigation.²³

7. The Evolution of Knowledge

A fundamental question is why knowledge is generated in the first place. Although it may appear overly philosophical to overly pragmatic economists, it must be posed in the quest for reliable micro-foundations with a potential to better inform our understanding of the behaviour of agents. The question is especially pressing if it is true that modern economic systems are ‘knowledge-

based', innovation is the engine of growth and knowledge-intensive businesses are growing components of advanced economies.

Following Popper, knowledge is a solution to a problem. The process of learning is the attempt made by individuals to make sense of the world and find solutions to problems (Coriat and Dosi, 1998). 'Making sense' entails (1) referring stimuli to pre-existing models of the world (2) articulating ideas (3) and generating propositions on the states of the world observed (Coriat and Dosi, 1998). In our framework of understanding, these propositions are messages triggered by reactions to the external environment (Holland, 1998).²⁴

Among the very many stimuli to which agents are subjected at any moment in time, which ones are taken up, elaborated and retained? How are new conjectures made, and how are old ones gradually abandoned? Some fundamental mechanisms by which knowledge changes over time show evolutionary properties and answers must be looked for in the interaction of humans with their environment. In this perspective, the development of knowledge is intrinsic to human life – and of course to the passing of time – in that it essentially is the highly sophisticated result of the struggle for survival of a species that is capable of developing and accumulating knowledge through culture (Aunger, 2010). Learning is a process through which agents improve their chances of survival by testing different ways of behaving in the environment where they operate.²⁵

The relationship between individuals and the environment is typically adaptive, but adaptation involves highly creative efforts, and cannot assume the connotation of a passive event-reaction process on the deterministic basis of their genetic endowments. In the evolutionary metaphor, various propositions about the state of the world can be made by agents and, so to say, compete for adoption. Campbell (1960) identified 'blind variation' as the principal source of novelty in the generation of relevant hypotheses. By 'blind' he meant neither 'irrational' nor simply 'random', but instead as 'lacking foresight'. Or to put it differently, he asserted the fundamental importance of trial-and-error learning. If in fact the results obtained from testing a solution to a problem were less than uncertain, then no radical novelty could be generated. Novelty can originate in the face of uncertainty only through experimentation, whose outcomes will reveal a 'selectworthy encounter'.

Selection among the relevant messages operates on the basis of their aptness in problem-solving activities, that is to say in their capability to solve a problem relative to the alternatives that are viable but have not worked in earlier trials.²⁶ In a Popperian fashion, they are tested until one fits the relevant selection criteria. Then, this proposition/command may be replicated by analogy within a knowledge structure as a response to similar problems or replicated within a certain population through the interaction of communicating agents faced with

the same problem. The message is therefore retained and replicated, thus inducing cumulateness in the evolutionary path of the system.

Agents are continuously presented with new problems. As time goes by the environment in which agents operate changes, whether independently or through the agents' own intervention. It follows either that over time problems change, hence that there is a need to find new adaptive responses, or that problems remain the same but new and better solutions must be found. When new solutions are found that are better suited to answer existing problems, some old solutions can gradually become obsolete. The process of 'substitution', which can never be perfect because different solutions activate different connections, is not instantaneous and the disappearance of old solutions (that is the process of 'forgetting') is a necessary part of the process since cognitive resources are not unlimited.

At the same time this is costly and not without waste. These costs are proportional on the one hand to the specificity of the efforts associated with the achievement of that particular solution, which may be lost completely in the process of developing new knowledge; on the other hand, they depend on the degree of interrelatedness of that solution within the overall system. The more systemic, the slower is the change likely to be. Not surprisingly, then, institutional change, which is systemic by definition in that it originates from the correlation of the individuals' behaviours, is particularly slow, as we have already mentioned.

Having a rule of selection, if knowledge is thought of as a solution to a given problem and all viable potential answers are also given, learning becomes by definition a statistical search in a given space, provided that the agents have enough time for collecting observations from reality. In this framework, a pure mechanism of induction would guarantee the identification of the best solution. But the difficulties of this perspective increase proportionally to the recognition that is given to the fundamental problem of uncertainty.

The first difficulty concerns the fact that knowledge is dispersed in society, as Hayek (1945) argued, so that agents do not have all possible solutions at their disposal to conduct their tests. As a consequence, the solution selected out could not be the best of all (a global optimum), of which they could not be aware at all, but simply a local optimum. The second difficulty is that agents cannot dispose of unlimited time and unlimited processing capacity, as Simon pointed out (1982), so that there is no guarantee that they can actually achieve even the (relative) best solution and, therefore, opt for a satisficing solution. The third difficulty is the fact that a problem can be framed in different ways in different contexts and the way in which it is framed may lead to different choices, as shown by Tversky and Kahneman (1986).

If interpreted radically, the idea that problems can be framed in different ways bears far-reaching implications for the study of social systems and is obviously dangerous for any strongly positivistic theory. The fundamental question, in fact, becomes: how is a problem identified and configured in the first place? As Arthur (2000) notes, this is an issue that goes very deep into the levels of complexity of human cognition (which is rarely considered in the domain of economics). Arthur (ididem) calls attention to the role of analogical thinking and makes a compelling argument when he notices that individuals face different problems distributed on a range that goes from easy to difficult ones, and – more subtly – from well-specified to ill-specified ones. Agents do not face problems but *situations*. *They* have to abstract and frame the problem.

Arthur (p. 52) observes:

...Framing [the problem] in many ways is the most important part of the decision process. To consider that framing you have to consider what lies between the problem and the action taken. And between the problem and the action lies cognition.

Interpretation of the information available is essential to spot and formulate the problem in such a way as to find a solution, if a solution exists. As agents differ, different will be their interpretations of the same data, because there is no meaning but in their minds.

Ziman makes a similar point (2000: 184):

...Research problems are not there for the ‘choosing’, or even for ‘finding’. They have to be *formulated* [our emphasis]. The world is not laid out for study in pre-ordained categories. Dame nature does not present the scientist with a list of carefully crafted questions like a well-made examination paper. In principle, each researcher has to make up for herself the problems on which her performance will be assessed. The highest peaks of scientific genius are not for sheer virtuosity in ‘solving problems’. They are reserved for the immortals who have posed these problems in the first place – by asking the right questions about an age-old mystery, by perceiving a genuine conundrum inside a mundane enigma, or by inventing tools that open up quite novel fields of enquiry.

Is there any room left for the notion of optimality from the viewpoint of the individual faced with a problem? Optimality can be envisaged in the framework of a dynamical system where, as already suggested, the system is drawn towards a stationary state (the elimination of the problem, or the ‘truth’) through mechanisms of information feed-back relative to given alternatives. In this framework, it is required that a probability distribution for all possible errors is

known, that large numbers of observations are available (otherwise statistical properties do not hold) and that there exists a one-to-one mapping of shock and response-action sets.

Unfortunately, large numbers of observations cannot be available in the presence of finite resources (time and cognition) and cause-effect relations are not strictly deterministic, because different, although overlapping, interpretations of the same stimulus are always possible and different rules of selection can operate, hence different states can originate from the same shock. As a consequence, while simple mechanisms of negative feedback are perfectly adequate to describe the transmission of information, they are not adequate to describe the development of knowledge. Most importantly, in the face of Knightian uncertainty, probabilities cannot be assigned to events and such events, including the attractor, cannot be specified a priori.²⁷

The development of knowledge shows non-linearities that are typical of complex system dynamics.²⁸ The process of knowledge creation displays strong positive feedback effects and its outcomes not only depend on the nature of messages generated through observation or exchanged through communication, but also on the whole ensemble of messages that already compose an agent's knowledge structure. Moreover, the way in which the system evolves depends both on the initial conditions and on the sequence of previous states, because both the initial structure and the sequence through which messages are internalised affect understanding.

Due to the creativity of agents in producing and elaborating messages, knowledge systems are able to internally generate new developmental patterns, that is new searches, and generate new attractors, that is new problems. The generation of novelty is therefore not only time-dependent but also endogenous, and the problem-solving process never reaches any equilibrium because the system is continuously generating new solutions as well as new problems. It is never possible to trace back the sequence of events that led to a specific state, because more than one sequence could have produced the same state and because stochastic elements cannot be ruled out; it follows that the process is also 'opaque' and irreversible. Being irreversible, sensitive to chance-events and subjected to positive feed-back, learning processes are typically path-dependent.

As regard to the system level, say very crudely the aggregation of a number of individuals, the same principles can be posited to hold, but while thought messages are unit of selection in the individual's mind, explicit messages communicated between individuals are instead relevant for the function and performance of a social coalition. Social structure determines the possibility of connection between messages dispersed among different agents. It enables and constrains the circulation of messages and fosters the association of ideas never

previously connected by bringing together and creating the conditions for interaction between different individuals. At the same time, the institution of collective mechanisms of selection and retention induces the emergence and diffusion of messages of higher relative fitness, so that progress can be envisaged as the increase in the average fitness of the responses given in the system to a socially perceived problem.²⁹

One last note must be added on the implications of serendipity in the process of learning. The recognition of the pervasiveness of change events is sometimes interpreted as a denial of the role of human purpose in evolutionary thinking. Ziman (2000: 217) discusses in some depth the epistemological significance of the ‘accidental discovery of something not sought for’ and writes:

...The key point is that serendipity does not, of itself, produce discoveries: it produces opportunities for making discoveries. Accidental events have no scientific meaning in themselves: they only acquire significance when they catch the attention and interest of someone capable of putting into a scientific context. Even then, the perception of an anomaly is fruitless unless it can be made the subject of deliberate research. In other words, we are really talking about discoveries made by the exploitation of serendipitous opportunities by persons already primed to appreciate their significance.

The very same argument is valid with regard to the emergence of business opportunities and is very helpful in highlighting the deeply creative effort of entrepreneurs who, well beyond the pure notion of ‘alertness’ (Kirzner, 1978), can spot an economic problem (a need) *by posing a question* in a way that has not been used before, and devise a viable answer by purposefully organising a frame for action. Social action – action is necessarily social because agents are parts of social coalitions and their actions are interdependent – is enabled and constrained by the structure of relevant connections among agents. Posing a new business question is a prerequisite for restructuring and diverting towards unexpected outcomes the cognitive and social structure of the economic system.

8. Self-Organisation and Self-Transformation

Exclusive focus on the single agent combined with a highly relativistic view of human knowledge can lead to extreme versions of methodological individualism that risk undermining the foundations of scientific research – especially when social sciences are concerned – and its principles of objectivity, generality and replicability. Although undeniably heterogeneous, agents share degrees of understanding and they are capable of correlated behaviours. If they were not, they could never be able to organise their lives in social groups. The

choice of how much diversity to assume or to investigate is a typical question of balance between the intellectual instances at stake and the problems posed.

Population thinking is one way out of methodological individualism in that it looks at collective interdependent behaviours without positing the homogeneity of agents. The notion of institutions is another, very much related, solution because it focuses on *shared* habits, norms and beliefs thus shifting upwards from micro to meso the level of analysis and while providing ground for empirical observation, it does not close the door to shocks induced by the action of single individuals on the basis of the unobservable dynamics of the mind. Attention must be paid to the fundamental structure of the system and to the evolution of the system over time. The organisation of action that is external to individual agents and not exclusively reducible to their knowledge (whether totally homogeneous or totally heterogeneous) strongly emerges as the main dimension of economic analysis, in which dynamics of communication function as fundamental mechanisms for organising collective action.

Learning occurs at the level of the individual, but it reverberates within and across groups in the co-ordination of economic activities.³⁰ Via communication, learning can be articulated between individuals, within and between teams and within and between firms. Above all, as Fransman (1994) reminds us, Penrose (1958) and Chandler (1977) saw in the creation of knowledge the fundamental reason for the existence of the firm and it is on the trail of their contributions that competence-based views of the firm are now well-established in the literature. But of course, given that there is no collective brain directly connecting the neural networks of individuals, the claim that teams and/or firms have knowledge is not rigorously true and therefore should always be kept as an abstraction or gross approximation. It is true that a great deal of documents may be produced inside the firm to communicate and store messages (storage is simply a communication opportunity deferred in time), and yet knowledge cannot reside but in the living memory and active judgement of individuals involved in the business. On this premises, the different levels at which individual learning becomes relevant correspond to different institutional settings whose norms govern interactions at the relative level.

The behaviour of individuals within teams, firms or other organisations (e.g. regulatory bodies) is systematically influenced by the enabling constraints imposed by formal and informal norms governing their interaction. Among the formal institutions we can count the set of monetary incentives and the binding terms of the contracts (e.g. non-disclosure agreements, allocation of property rights for patents, right to maternity leave, etc.), while among the informal ones we can include tacit codes of practice and collective habits (e.g. peer-review in the selection of scientific papers). Similarly, formal and informal norms sustain social interaction between individuals who are members of different teams and organisations. Linkages external to the organisation are essential, for example,

to achieve the economic goal of producing a complex good (or delivering a composite service) or the goal of connecting production and consumption activities. In this latter case, firms must engage in processes of interactions with buyers which are instituted in society as guidelines for the creation and sustainability of the mechanisms of market exchange. Interactions with regulators (e.g. the public *personae* or pragmatic institutions embodying the norms of exchange) are – needless to say – as important as interactions with customers. Overall, a great variety of interactions take place at any point in time at any level and across levels in an economic system (individuals, teams, business units, firms, etc...), which raises a fundamental problem of co-ordination.

Hayek's interpreted the Smithian notion of the 'invisible hand' in terms of the self-organisation of a decentralised system of free economic enterprises. From this perspective, the spontaneous emergence of order is a collective response to commonly perceived – and 'correlatedly' understood – problems whose solutions require the co-ordination of the agents' actions. Co-ordination is 'spontaneous' not in the sense that it is unconscious or deprived of purpose, but in the sense that it is achieved by individuals whose knowledge is limited and heterogeneous, and whose actions are structurally interdependent, in the absence of a central authority working a 'super-brain'. Moreover, the system cannot be treated as an integral space where all entities are commensurable and continuously differentiable, because different problems are independently posed in different parts of the system (Potts, 2000).

Capitalistic market economies essentially are decentralised self-organising systems and their macro-behaviour depends on the 'augmenting' interaction – and not simply on the aggregation – of the subsystems that compose it (which in turn are influenced by the macro-patterns generated by their interaction). The bases for the organisation of social action are the cognitive faculties of individual agents, who need to communicate to solve problems which are collectively recognised as relevant. Co-ordination is made possible by shared knowledge of rules.

Any act of communication involves the introduction of semantic noise, that is to say the germs of new connections, because agents differ in their interpretation of messages. While information diffuses, knowledge develops locally and idiosyncratically and the variety of knowledge system, that is the network of individuals engaged in communication, grows irreversibly with the number of interaction and with the 'cognitive' variance of the population considered. If agents are heterogeneous in their knowledge and the way they decode and understand new messages depends on their knowledge, then knowledge develops differently in different parts of the social group. Therefore knowledge does not simply grow but changes any time it is enriched of new connections by reaching out to new agents.

How are new connections introduced into the economic system? One sensible answer, as we have already anticipated, is through the action of marginal agents capable of bringing to the fore novel solutions. This seems to be precisely the role of the entrepreneur, as Schumpeter insisted. In fact, he saw in the entrepreneur (or in the entrepreneurial function of large firms) the source of discontinuity (or the origin of parametric change) *par excellence*. The entrepreneur turns unlikely connections between disjoint ideas into articulated business plans, and, if successful, triggers a chain of related changes in the organisation of production and consumption activities of a social group. Among all agents, it is the entrepreneur that exerts a most fundamental de-correlating function when he/she imagines a new solution to an existing problem by asking a different question. The process of de-correlating existing knowledge may not be easy or uncontroversial, but it is the necessary – ‘destroying’ – counterpart of the creation of new correlations.

One major implication of this is that at the system level there cannot be self-organisation without self-transformation. Posing a different question means inducing a qualitative change into the system that has the potential to wholly or partly reconfigure it because of the interdependent nature of its components. This is particularly important for capitalistic market economies, whose engine of growth is the endless possibility of accumulating, recombining and transforming economically useful knowledge through the generation of innovations, which change the structure and nature of a number of related products, processes and practices along their diffusion paths, which in turn contribute to change their characteristics and aims because their very diffusion activates different connections in different parts of the system.

It must also be emphasised that changes in knowledge are also linked to changes in social structure. If agents know different things, the introduction of elements of novelty redistributes the value and the use of their skills and competences, and as a consequence the nature and the extent of their power between and across the coalitions to whom they belong. Conversely, changes in social structure alter the value of different sets of skills and generate different opportunities for learning because they stimulate different interactions or interactions of a different nature.

Changes in knowledge and changes in social structure are not smooth and continuous. It is well known, and Fischer and Frölich (2001) remind us, that fundamental discontinuities in the evolution of industries can be observed in the rise of dominant designs (Utterback and Abernathy, 1975), paradigm shifts and the emergence of technological regimes (Nelson and Winter, 1982; Dosi, 1982), which are the aggregate outcomes of turbulent developments of knowledge in phases of ferment. They emerge when agents move to areas of criticality where the system can, and does, ‘make the jump’. Dosi’s (1988) notion of technological paradigm relates to the need of accounting for the emergence of

structural, qualitative and parametric novelty, which probably remains the most fundamental challenge faced in the economic analysis of innovation.

The amplification of the effects of radical innovations from the micro- to the macro-level is the path to increasingly correlated knowledge among agents, of which public institutions (standards, legal entities, regulatory bodies, etc.) are the explicit representations in society. Because similar new connections are activated in different agents, then the process of change is at the same time the process by which new product, processes and practices are normalised within the system, so as to render old alternatives obsolete and ultimately become obsolete themselves when better solutions are found to the same problems or following to changes in other parts of the system where solutions to problems collectively perceived as more relevant induce further problems in related domains.

9. Concluding Remarks

We started this discussion by focussing on some dimensions of the economic problem of knowledge. Emphasis was put on the notion of interactive learning and a stylised account of the process of communication was given in which de-codification processes, somewhat left in the shadow by previous contributions, complement codification processes. The inclusion of the receiver's part of the story permits to appreciate the role played by interpretation and understanding in the development of knowledge. Interpretation and understanding, on the one hand, limit the extent to which a message can be absorbed and valued by any individual, since all individuals are different in their past experience, hence in their knowledge. On the other hand, they account for the continuous introduction of elements of novelty into the knowledge structure of the receiver which can significantly alter the latter's potential for the generation of new messages.

Clearly, the kind of knowledge involved in economic processes is well beyond the notion of information about market prices; it includes substantive knowledge about quality and quantity of goods and services, properties and costs of technologies, opportunities and risks of business enterprises, visions and strategies of firms and regulators, preferences and practices of buyers. In the face of changing environments, economic agents act and re-act by exchanging information, which can diffuse, and by developing new knowledge, which cannot diffuse without being transformed.

Agents organise their activities in changing social networks and knowledge spaces. Generating and absorbing new knowledge become the pre-conditions for making reasonable choices and undertaking meaningful economic actions. In this light, as Hayek already suggested (1945), the continuous and recursive process of creation, communication, absorption and use of economically

relevant knowledge can be said to be the main activity of economic agents. A major consequence of this argument is rather straightforward, as Stiglitz has persuasively argued (2000): the creation, communication, absorption and use of knowledge strongly emerges as the most fundamental problem of economics.

Space constraints do not allow us to develop in full the connections and extensions of the main arguments of this paper to institutional theories, but this is clearly one important avenue for further research. While institutional structures guarantee order and continuity over time, the possibility of introducing change within the system can never be ruled out as long as agents differ in their knowledge and in their understanding of the countless bits of information continuously percolating within and across social structures or directly obtained from the observation of reality. The resulting view of learning is that of a process that shows fundamental properties of a complex process, being modular, adaptive, path-dependent, context-dependent, open-ended and fundamentally creative in that it is capable of internally generating radical novelty.

The diffusion of information and communication technologies have created an increasing number of opportunities to transport information in time and space at decreasing costs, increasing capacity, speed and quality of transmission (Antonelli, 1992). By augmenting the connectivity of the system, ICTs have provided the necessary conditions for an unprecedented increase in the amount and variety of information produced and exchanged, therefore multiplying the opportunity for the creation of knowledge by increasingly connected individuals. What is new about the so-called knowledge economy is not that it is uniquely based on processes of knowledge generation, because there cannot be economies that are not based on knowledge (Metcalf, 2001; 2002).

Economies may differ in their governance, structures and performance, but they must be all based on the knowledge of the individuals that contribute to them. What is really new about advanced capitalistic economies is the intensity, frequency and pervasiveness of processes of information exchange – including increasing access to formal education – which open up countless opportunities to recombine knowledge scattered in society and across societies.

Capitalistic systems are governed by rules that are particularly appropriate to take full advantage of the open-endedness of learning dynamics, where the definition of attractors is subjective and fallible. The related major implication for economics was clearly identified by Alchian (1950) when he suggested that if there was no uncertainty – which entails the opportunity to develop new knowledge and new business opportunities – there would be no profits.

Goals can be failed also because decisions are taken in conditions of ignorance of all the relevant elements that would be necessary to guess correctly and because these are affected by collective processes where the choices of agents

are interdependent. Knowledge and uncertainty emerge as the two sides of the same coin, where one cannot exist without the other. If there were no uncertainty, there would be no need for knowledge; if there was no knowledge, nothing but random actions could be undertaken, and observed, in the face of uncertainty. The quest for knowledge can never stop because individuals – and especially free individuals living in tightly interconnected systems – are continuously confronted with situations that are turned into problems that induce solutions that generate new situations... in the self-organising, self-transforming and open-ended process of evolution of social systems.

The history of capitalistic economies is punctuated by failures, as well as of successes, and the history of technologies is rich of examples that show the limitedness of ‘rational’ foresight presented with radical novelty. Freeman and Soete (1997) recall a number of cases where expectations on the market potential of major innovations were dramatically wrong, quantitatively and qualitatively. Among them are polyethylene, PVC and synthetic rubber, the personal computer, the transistor, the robot, numerical control devices, fuel cells, nuclear reactors, the Concorde. To these, as Fransman (2003) suggests, at least laser and mobile telephony technologies could be added.

And although disappointing for supposedly-rational observers, yet the fallacy of prediction is by itself a guarantee of the opportunity that agents have to continuously imagine new options, developing alternative visions of the world and finding new solutions to problems, as Shackle (1979) so strongly emphasised, and Loasby (1999) does not fail to remind us.

Notes

1 Granovetter (1985: 483) argues that in the utilitarian tradition of classical and neoclassical economics, human action is treated as under-socialised. While this may hold true for the former, ‘asocial’ seems to better fit the latter.

2 See Arrow (1962, 1969), but also Nelson (1959).

3 The emerging debate on the increasing importance of intellectual property rights in modern markets has probably played an important role in the selection of this particular instance.

4 Other major references are included in the special issues of the Cambridge Journal of Economics n. 23(2) (1999) and Research Policy n. 30(9) (2001), which are entirely dedicated to this problem.

5 See Geroski (1995) and Breschi and Lissoni (2001) for a discussion.

6 Karlsson and Manduchi (2001:102) notice: ‘The latest development notwithstanding, the literature on knowledge spillovers is still, in many respect, unsatisfactory. The knowledge concept used is seldom defined. Knowledge spillovers are often dealt with by imposing highly restrictive and arbitrary assumptions; furthermore, the exact mechanisms through which the spillovers take place are not discussed’.

7 It must be stressed that an illuminating paper by Robert Solo (1966), titled ‘The Capacity to Assimilate Advanced Technology’, anticipated the notion of absorptive capacity with an in-depth discussion of the non-transferable components of artefacts and production techniques. Solo already made very clear, as Nelson (1992), among others, did later with the notion of ‘National Systems of Innovation’, that the absorption of new technologies requires social action and social competence in the recognition of the opportunity, understanding of the technology, in its adaptation to contingent needs, and, last but not least, in shaping the environmental and institutional context of adoption. In other words, he stressed the truly creative role of the adopters and the crucial importance of cognitive processes at a macro level of analysis.

8 We take the view that knowledge is a *structure*, or *ensemble*, and not simply a ‘stock’, as persuasively argued by Saviotti (1998), Cowan et al. (2000), Ancori et al. (2000), Steedman (2001), Potts (2001), Cohendet and Meyer-Kramer (2001) and Metcalfe and Ramlogan (2001).

9 According to Ferdinand De Saussure (1857-1913/1985), father of modern linguistics, messages are first of all combinations of *signes*. Signs, and therefore messages, consist of a *signifier* and of a *signified*. With some simplifications, we may take the signified as the meaning of the sign and the signifier as the ‘form’ of the sign. Messages, therefore, have a semantic structure and a

phenomenological structure which co-exist in the same entity. A code defines rules of association between the signifier and the signified. As a consequence, codification is a process by which meaning (i.e. mental content) becomes message through the use of a semiotic code.

10 The term ‘data’ could be used instead of ‘information’. In so doing, we could also follow Machlup’s (1980) suggestion to use information in the sense of ‘the process of informing’, which would become the production of messages embodied in sequences of data that are transferred from agent to agent.

11 The definition of information provided above holds because the process of codification entails the modulation of airwaves aimed at the intelligible production of sounds.

12 Therefore, when words (or music) are written down or recorded, they are commodified and not just codified, since they are anyway codified when enunciated (or performed) independently of their storage. Interestingly, it is the latter that truly enables the ‘privitisation’ of information.

13 It is not by chance, in fact, that in the domain of innovation studies the rich research agenda originated by the Polanyian notions of tacit and codified knowledge has organically grown together with the emerging debate on knowledge markets and on the new challenges posed to firms and regulators by the allocation of intellectual property rights in growing new sectors such as those of software and biotechnologies.

14 The aforementioned costs can be conceived as ‘sunk’.

15 As a consequence, there is no doubt that high fixed opportunity costs exist both on the sender’s and on the receiver’s side, and they need to be taken into account when estimating (1) the probability that communication is effective, and (2) the overall cost of the process. This is expressed very clearly already in Cowan and Foray (1997).

16 The connection between differences in capabilities and variability of interpretations is a fundamental principle of the Penrosian view of the firm (1959).

17 We could distinguish ‘correlation in depth’ from ‘correlation in breadth’, according to the intensive vs. extensive quality of the connections between agents. Agents could be said strongly connected when their cognitive sets show considerable overlaps, or else weakly but broadly connected when overlaps are minor but common to a number of agents. On the basis of the distribution of knowledge sets over these dimensions, it is possible to conceptualise an ‘ecology of knowledge’ in the economic system.

18 For an interesting discussion on the relationship between innovation and knowledge from the viewpoint of Keynesian probability theory, see Crocco (2003).

19 This introduces into the discussion the idea that areas of *criticality* exist, from which the system can develop very different – and unforeseen – behaviours over time.

20 In attempting to map agents according to their cognitive distance, a fundamental problem of metric would be encountered. The same agents are simultaneously more or less close in a number of dimensions; which ones are relevant to define their relative distance?

21 March's (1991) distinction between *exploration* and *exploitation* works very much on the basis of the same principle.

22 He brings as examples computer programmes developed for X-ray scanning of the brain and then applied to seismic prospecting for oilfields; biological enzymes used as catalysts in heavy chemical plants; the microscopic study of radiation damage in plastic films used to detect cosmic rays.

23 Space constraints do not allow us to digress on the problem of the cognitive foundations of institutions. An in-depth discussion of the link between knowledge and markets can however be found in Mina (2009).

24 The capability of creative thought is particularly broad for humans, who have evolved in the course of time rather extraordinary systems of symbolic communication which greatly enhance on the one hand their chances of discovering the properties of their environment, thus favouring active intervention upon it, and on the other the chances to externalise and transfer their acquired knowledge in time and space.

25 This begs the question whether it would be possible to be living (or rather 'surviving') and not knowing.

26 The unit of variation and selection implicitly taken here is a message in the form of a proposition (that is an association of concepts) about states of the world. The concept of memes (Dawkins, 1995) is often used in evolutionary epistemology. Those of 'routine' (Nelson and Winter, 1982) and 'technique' (Mokyr, 1998) are instead increasingly familiar to scholars of innovation. If intended as a produce of symbolic communication, they fit rather well the present discussion. For example, Mokyr (ibidem) defines a 'technique' as '...nothing but a set of instructions, if-then statements (often nested) that describe how to manipulate nature for our benefit' (p. 122). For the broader implications of the definition of the unit of selection, the reader is referred to Hodgson (1993a) and Ziman (2002).

27 Optimality is target-specific. If the target is uncertain, an optimum cannot be computed.

28 There is no generally accepted definition of complexity. As principal reference for this text, we follow Allen (1990) and Arthur, Durlauf and Lane (1997).

29 And the argument could be further developed that what is maximised is the rate of growth of the average fitness of solutions to problems at the system level. The problem is; what dimensions matter for the fitness function?

30 Developments in organisational theory make the point very clearly. See, for example, Mohrman et al. (1995), Crossan et al (1999), Katzenbach and Smith (1999).

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