A critical survey of J. K. Arrow'S theory of knowledge

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INTRODUCTION

The empirical studies of Tinbergen (1942), Abramovitz (1956), and Solow (1957) have demonstrated that only part of the historically observed increase in productivity can be explained by the increase of capital relative to labor. The greater part of this increased productivity is due to our increased knowledge of the world and its laws. These results do not directly contradict the neoclassical view of the production function as an expression of technological knowledge. All that has to be added is the obvious fact that knowledge is growing in **time**. Naturally this implies that knowledge is an economic good, more precisely a factor of production, for there is a positive return to an increase in knowledge. But then the problem which arises is that the market for knowledge as a good is not well developed.

In fact, one of the major contributions of Arrow in the sixties consists in his exposure of the imperfect feature of market for information or knowledge[3]. Although Kenneth Arrow is probably best known for his contributions to methods of direct decision making and the theory of ideal market decentralization , he laid much of the groundwork for subsequent discussion on alternative methods of organization. By pointing out and developing the relationships between the competitive allocation mechanism and other planning procedures , he caused us to focuss

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[3] Arrow indifferently employs "knowledge" and "information": "I speak here of 'knowledge', but one could equally speak of 'information'. I avoid the latter word here because of its technical implications in the theory of communication" (Arrow, 1965a, p. 192).

on issues such as information gathering , communication efficiency , and transmission costs in deciding among forms of economic organisation . As many other economists , I think " it is fair to say that he [Arrow] set an agenda for the future in his presidential adress to the American Economic Association in 1974 and in his Fels lectures (**The Limits to Organization**) ... He pointed out the need for a better understanding of information costs and how they should be measured ; he suggested that many of the problems faced in understanding the structure and operation of large organisations could be analyzed only by bringing **information** and **communication channels** more directly into the agenda of economists ; and he advanced the view that the concept boundaries between **internal** and **market** allocations should be analyzed in those terms ." (Heller S. , and Starrett D. A. , eds. , vol. III , part II , p.189). The purpose of this article is to explore different aspects of Arrow's theory of information and to sketch some critical orientations on the issue which have been raised and discussed widely in recent litterature that bypass the original analytical framework of Arrow's theory.

Ruminating upon the specificity of information as a " good " in competitive markets , Arrow notes that "strictly speaking, knowledge lacks two properties that are important for a good that is to be bought or sold freely on competitive markets : 1) it can be possessed only imperfectly, and it is difficult to prevent others from using it ; 2) the use of knowledge in productive activities obeys the law of increasing returns, since the given need for knowledge in a given activity is independent of its scale. It follows from these remarks that neither the demand for nor the supply of knowledge satisfies the conditions of a competitive market." (Arrow 1965a, pp. 191-192). Consequently, any analysis with regard to the impact of knowledge on productivity and economic performance should start by an inquiry on the nature of information.

Henceforth , the first chapter will discuss the nature of information. The second and the third chapters will treat respectively the production and the transmission of knowledge. Finally , the fourth chapter will be consacrated to the limits of Arrow's theory in light of recent litterature on the economics of information.

I) THE NATURE OF INFORMATION

The neoclassical approach suggests that competition ensures the achievement of a Pareto optimum under certain hypothesis. It usually assumes, among other things, that 1) the utility functions of consumers and the transformation functions do not display indivisibility (more strictly, the transformation sets are convex). The first hypothesis conceals two assumptions of the usual models: it prohibits uncertainty in the production relations and in the utility functions, and it requires that all the commodities relevant either to production or to the welfare of

individuals be traded on the market. This will not be the case when a commodity for one reason or another cannot be made into private property.

We have, then, three of the classical reasons for the possible failure of perfect competition to achieve optimality in resource allocation: indivisibilities, inappropriability, and uncertainty. For Arrow (1962a, pp. 104-120; 1962b, pp. 129-142; 1965a, pp. 191-199), the interesting fact about the information (or knowledge) is that it is subject to all of the three elements of market failure.

I-1. Uncertainty

Information becomes a commodity whenever uncertainty is present (Arrow, 1962a, p.110). Suppose that in one part of the economic system an observation has been made whose outcome, if known, would affect anyone's estimates of the probabilities of the different states of nature. This kind of subjective probability distribution, due to the uncertainties about the different possible states of the world, has first been introduced to economic literature by M. Allais (1953, pp. 269-290), K. Arrow (1959, chapter 3, volume 2, collected works), G. Debreu (1959, chapter 7). Such observations arise out of research, but they also arise in the daily course of economic life as a **by-product** of other economic activities. An entrepreneur will automatically acquire a knowledge of demand and production conditions in his field which is available to others only with special effort. Information will "frequently have an economic value, in the sense that anyone possessing the information can make greater profits that would otherwise be the case (Arrow 1962a, pp. 110).

I-2. Indivisibility

A given piece of information is by definition an indivisible commodity, and the classic problems of allocation in the presence of indivisibilities appear here (Arrow, 1962a, p. 112). The owner of the information should not extract the economic value that 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. In the absence of special legal protection (for example, patent laws), 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 cost or no cost. Thus the only effective monopoly would be the use of the information by the original possessor. This, however, will not only be socially inefficient but also may not be of much use to the owner of the information either, since he may not be able to exploit it as effectively as others. "With suitable legal measures, information may become an appropriable commodity. Then the

monopoly power can indeed be exerted. However, no amount of legal protection can make a thoroughly appropriable commodity of something so intangible as information."(Arrow,Ibid.)

I-3. Inappropriability

The demand for information also has uncomfortable properties. In the first place, the use of information is certainly subject to indivisibilities. The use of information about production possibilities, for example, need not depend on the rate of production. In the second place, "there is a fundamental paradox in the determination of demand for information ; its value for the purchaser is not known until he has the information, but then he has in effect acquired it without cost. Of course, if the seller can retain property rights in the use of information, this would be no problem, but given incomplete appropriability, the potential buyer will base his decision to purchase information on less than optimal criteria." (Arrow, 1962a, p. 111)

It follows from the three afore-mentioned properties of information that the creation of a perfect competitive market for information is impossible. (Arrow, 1962a, p. 111; 1965a, p. 192; 1965b, p. 204)

The two principal problems in the analysis of information (or knowledge) as an economic good are those of production and transmission. In the first stance, we attempt to present Arrow's theory of the production of knowledge; then we will examine his position on the transmission of knowledge.

II) PRODUCTION OF KNOWLEDGE

According to Arrow, production of knowledge can be realized in two ways : 1) practice ; 2) research. The first way, practice, is what the great American philosopher and educator John Dewey has named "learning by doing". In his inquiry on the fruits of the social division of labor, A. Smith (1776) study the positive feedbacks of this type of learning (Smith, 1970, p.112). According to all theories of learning, people learn from experience. Given a problem, the individual makes explanatory responses and observes what happens. He chooses and retains responses that satisfy ; he rejects the responses that do not give satisfaction. It is the experience of problems that motivates learning, that is, the increase of knowledge.

However, one can start from a general scientific principal (nuclear fission, for example) and seek its field of application. In this case, we are dealing with a second way of learning, namely the research. Both methods (practice and research) lead to increased knowledge. (Arrow, 1965a, p. 192).

A production function, if it shifts as a result of increased knowledge, can shift in many ways. In a two-factor model, Hicks spoke of "capital-saving" and "labor-saving" innovations and raised the question of whether the bias is itself induced by economic considerations (J.R. Hicks, 1939; see also Arrow, 1961, pp. 225-250). Fellner (1962) convincingly argued that factor prices, per se, should have no tendency to cause bias, since the aims of the entrepreneur is to minimize total costs. Kennedy (1964) then sought to carry the Fellner analysis further by introducing explicitly the trade-offs between different possible biases in innovation. Kennedy, like many other writers, had tended to replace the Hicks classification by introducing a more explicit and restricted model of technological change, namely, factor augmentation:

$$Y=F[A(t)K, B(t)L]$$

where Y is output, K is capital, L is labor, and A(t) and B(t) are the total augmentations of capital and labor, respectively. Then there is postulated a "transformation function" for knowledge, in the form of a trade-off among the rates of growth of A and B and research expenditures. "Knowledge" as reflected in the variables A and B, appears as an input to physical output, and we then need to supplement the ordinary production relation with an additional relation determining these newly defined inputs.

The originality of Arrow's contribution relies in his criticism of Kennedy's model and his contention that technological progress is in the first instance a reduction in uncertainty. According to Arrow (1969, pp. 297-306), the production of a research and development effort is an observation on the world that reduces its possible range of variation. The outputs of different research projects are qualitatively different ; there is no gain in acquiring the same information twice. The production of knowledge is thus basically different in character from the production of goods, where successive items can be qualitatively identical.

Research and development are thus intimately connected with the problems of uncertainty reduction. Let the term "activity" be used as usual for any process described by inputs and outputs, but we are particularly interested in the case where the outputs are not known with certainty. It can easily happen that the outcomes for different activities will be dependent random variables in the sense of a subjective probability. The case most interesting from the present point of view is that where there is an underlying unknown parameter on which the probability distribution of outcomes for the different activities depend; then observing the outcome of one activity changes the a posteriori distribution of outcomes of the other. Arrow suggests the Bayesian language to be used for formulating this kind of subjective probability: "If I really believe that a pair of dice is fair, observing any outcome is of no use in predicting a subsequent one. But if I suspect bias and I express my suspicions by an appropriate subjective

probability distribution over the possible outcomes, then observing an outcome certainly does change my subsequent expectations in accordance with Bayes's theorem" (Arrow, 1969, p. 299).

Thus, an activity will in general have two valuable consequences: **the physical outputs themselves**, and **the change in information about other activities**. On the basis of this conceptual framework, Arrow proposes to classify two methods of producing knowledge. In production of knowledge by practice ("learning-by-doing"), the " motivation for engaging in the activity is the **physical output**, but there is an additional gain in the information, which may be relatively small, that reduces the cost of further production" (Arrow, 1969, p. 300). In production of knowledge by research ("search")" **the actual output** (for example, of nylon) is of **negligible importance compared to the information gain**- a posteriori the probability that a substance with the properties of nylon can be produced is now 1, whereas a priori it may have been a small figure." (Arrow, Ibid.)

Once these polar cases are presented, it becomes clear that intermediate cases are possible, and in fact the majority of research and development expenditures are actual steps in the production process, such as design, engineering, tooling, manufacturing, and marketing start-up costs (see for example: Mansfield, 1968, p. 106). Each stage involves uncertainties with regard to costs and, at the end, with regard to demand. At each stage, then, something is learned with regard to the probability distribution of outcomes, for future repetitions of the activity. At the same time, the physical outputs are expected to be directly valuable.

II-1. Learning-by-Doing

For Arrow, learning is the product of experience and it can only take place through the attempt to solve a problem and therefore only takes place during the activity. In this respect, learning-by-doing is mainly the outcome of "previous experiences in modifying the individual's perception" rather than "insight" in the solution of problems (Arrow, 1962b, p. 158). Moreover, Arrow cocedes that learning associated with repitition of essentially the same problem is subject to sharply diminishing returns (Arrow, Ibid.). There is an **equilibrium** response pattern for any given stimulus, towards which the behavior of the learner tends with **repitition**. To have steadily increasing performance, then, implies that the stimulus situations must themselves be steadily evolving rather than merely repeating.

The following empirical evidence can be cited to support Arrow's hypothesis :

1) The most dramatic evidence is based on the observations of the aeronautical engineer T.P. Wright (1936). In the production of airplanes of a given model, the quantity of labor necessary for each airplane diminishes from one to the next according to a very exact simple formula specifically, the labor used for the Nth airplane of a given model is proportional to N-0,3 (Arrow, 1962b, p.159)[4]. Hirsch (1959) has shown that a similar law holds for the construction of some types of machines. These relations are called **progress curves**.

2) The statistical studies of Kendrick (1961, table 60, p. 207) and Salter (1960, pp. 123-124) have shown that industries whose production increases most rapidly have the most rapid increase in productivity (cited in Arrow, 1965b, p. 193).

3) Erick Lundberg (1961, pp. 129-133) wrote about a Swedish steel mill, Horndal, that had no investment for fifteen years; nevertheless, its output per worker increased by 2% per annum (cited in Arrow, 1962b, p.159).

It follows from the above-mentioned empirical evidence that knowledge derived from "learning-by-doing" is a **by-product** of production or of investment. In research, on the contrary, it can be said that knowledge is the **primary product**.

Several authors have advanced the hypothesis that productivity grows differently according to what form of production is involved. P.J. Verdoorn (1959, pp. 433-434) has suggested the application of progress curves at the national scale. T. Haavelmo (1954, secs. 7.1, 7.2), among other models, has proposed one in which knowledge is a factor of production, while it is itself produced by investment. Nicholas Kaldor (1961, sec. 8, 1961-1962, pp. 176-177) has proposed a relation between the rate of increase in labor productivity and the rate of investment per worker. Like Haavelmo and Kaldor, Arrow considers investment to be the moving force of learning. Furthermore, Arrow assumes that the process associated with a given machine obeys a law of fixed coefficients ; for each machine, then, a given quantity of labor is needed to obtain the given output. New machines are better than old ones .

Let G be the cumulative gross investment. Let
E(G)= labor used on the Gth machine,
Y(G)= capacity of the Gth machine,
X= total output
L= total employment of labor

[4] Arrow's interest in the aeronautical engineering is rooted in his period of military service during world war II as a weather officer. See, Arrow, 1949, pp. 1-23.

The function E(G) decreases or at least does not increase with G ; Y(G) increases or at least does not decrease. Therefore, the newer machine is always used in preference to the older. Finally, let G' be the serial number of the oldest machine used. Then

$$(1)\ X=\int_{G'}^{G} Y(G)dG$$

$$(2)\ L=\int_{G'}^{G} E(G)dG$$

The variables X, L, G, and G' are all functions of time. If one assumes full employment of labor, which is the most natural hypothesis for the analysis of growth, L(t) is the labor force, and it is given exogenously. One can find G'(t) from (2) and then X from (1). Let U(G) and W(G) be the indefinite integrals of E(G) and Y(G), respectively. U(G) and W(G) are increasing and possess

inverse functions, U^{-1} (u) and W^{-1} (v).

(3) X=W(G) - W(G')
(4) L=U(G) - U(G')
from (4) we have : (5) $G'= U^{-1}$ [U (G)-L]
and therefore,
(6) $X=W(G)-W\{U^{-1}$ [U (G)-L]}

Which is a production function in a new sense. Output is a function of total gross investment up to the present moment, although only the portion beginning with G' is used. Arrow shows that the production function (6) obeys **the law of increasing returns to scale** (see Arrow, 1962b, pp. 161-179 ; 1965a, pp. 194-198). In Arrow's model, technical progress by doing has the effect of creating a law of increasing returns. But for this purpose, he includes in the definition of capital the memories of obsolete machines. Moreover, Arrow's model, which is in our view the modelization of A. Smith's analysis of positive feedbacks, proves that the greater the rate of growth of wages and the rate of increase of total output, the greater is the rate of growth of the labor force. It is a strongly anti-Malthusian conclusion. Evidently, the growth of productivity can be more effective if the labor force increases more rapidly. The greater increase of output in turn causes a more rapid increase of saving and therefore of investment, which makes the process of learning grow still more rapidly.

II-2. Search

Contrary to the learning-by-doing case, Arrow does not propose any model for "search". In fact, such a model was later formulated by R.R. Nelson and S.G. Winter (1980, 179-202). However, Arrow, like Nelson and Winter, acknowledges the close relation between "search" and uncertainty. According to Arrow, "The central economic fact about the process of invention and research is that they are devoted to the production of information. By the very definition of information, invention must be a risky process, in that the output (information obtained) can never be predicted perfectly from the inputs" (Arrow, 1962a, p. 111). By a "risky process", Arrow means the subjective probability distribution of outcomes in a Bayesian sense. Borrowing Langlois terminology (Langlois, 1984) inspired by the Knight's famous distinction between risk and uncertainty (Knight, 1933), we can suggest that a "risky process" in Arrow's sense corresponds to a "parametrical uncertainty" and not a "structural uncertainty". Parametric uncertainty refers to lack of knowledge regarding the parameters of the problem. This type of uncertainty is combined with knowledge of the structure of the problem and all possible states of the world. Structural uncertainty, on the other hand, involves lack of information about the fundamental nature of the problem and the type of outcomes that are possible. For Arrow, search as a "risky process" is riddled with uncertainty, nevertheless this uncertainty has a parametric or stochastic nature.

Our discussion regarding the production of information in Arrow's analysis may be summed up in the following taxonomy.

Production of Information

Type of Information Production	Learning-by-doing	Search
Type of Product	Information as a by-product of output or investment	Information as a primary product
Type of Market	Imperfect market due to uncertainty,indivisibility,and inappropriability	Imperfect market due to uncertainty, indivisibility, and inappropriability
Type of Uncertainty	Parametric uncertainty (Bayesian procedure)	Parametric uncertainty (Bayesian procedure)
Change in Phy. Output	Primary (progress curves)	Negligible
Change in Information	Negligible	Primary (risk and moral hazards)
Returns to Scale	Continuous and increasing(positive feedback)	Discrete and increasing (positive feedback)
Time	Endogenous	Endogenous

Modelisation	Present (a new function of production)	Absent
Type of Analysis	Dynamic equilibrium (intertemporal)	Dynamic equilibrium (intertemporal)
Type of Learning	Individual rational learning (dexterity of individual worker)	Individual rational learning (talent of the inventor)
Basis of Learning	Experience,problem-solving capacity (insight : negligible)	Application of a general scientific principle

As it can be inferred from this taxonomy, for Arrow, the production of information is intertemporal (Arrow, 1962c) and riddled with uncertainty (although a parametric one). Moreover, the information market is by its nature imperfect.

In his recent contributions on the economy as an "evolving complex system", Arrow particularly underlines the capital importance of these phenomena : "So far, the presentation has taken no account of time.... On the hypothesis that markets exist for all commodities at all times, the general competitive equilibrium model implies a time path of **equilibrium dynamics**. The hypothesis that all markets for all future times exist today is, of course, unrealistic, but it is equivalent to the assumption that all individuals correctly anticipate all future prices, the so called **rational-expectations hypothesis**. Furthermore, much recent analysis has gone into models which modify the hypothesis of complete markets by assuming that some markets for future commodities do not exist today and are not replaceable by expectations." (Arrow, 1988, p. 276).

Finally, it is noteworthy to mention that the standard assumptions of equilibrium theory, such as diminishing returns, concave utility functions, etc. manifestly cannot be applied to the production of information which is marked by positive feedback and exponential explosions.

III) TRANSMISSION OF KNOWLEDGE

For Arrow, the understanding of transmission of knowledge is of special importance in two of the key socioeconomic problems of our time: international inequalities in productivity and the failure of the educational system in reducing income inequality (Arrow, 1969, p. 302). The two problems have a considerable formal similarity. If one nation or class has the knowledge that enables it to achieve high productivity, why is the other not acquiring that information? That a nation or class has a consistently high productivity implies a successful communication system within that nation or class, so the problem turns on the differential between costs of communication within and between classes. Arrow writes: "The productivity differences among nations at a given moment are in great measure differences in the state of their

knowledge, and these differences can exist only because transmission is so slow" (Arrow, 1965b, p. 192). Arrow does not evidently assert that difficulties in communication of information are necessarily the sole source of total factor productivity differences. He concedes elsewhere that there can be withholding of information to perpetuate monopoly positions ; and both in foreign trade and in economic relations between the races, "income differentials can arise from exploitation" (Arrow, 1969, p.303). Nevertheless, for Arrow, communication problems are a "major and perhaps predominant source of productivity and income differentials" (Arrow, Ibid.).

What are the causes of these differential channel costs? Replying to this question, Arrow remarks the role of **personal contact** in diffusion of information. Mass media may provide some overall alertness to change, but, except for the most alert and daring innovators, it is the example and the advice of those known personally that are apparently most potent in securing acceptance of innovation. Arrow suggests two principles for casting light on the basic factors at work in the difficulties of transmission of knowledge across nations and through educational system :

1) A channel has greater capacity if the receiver regards it as more reliable. This is why personal contacts are frequently so important.

2) To a large extent, channels of communication serve purposes other than the diffusion of innovations (for example, friendship and convenience) and the direction of diffusion may be dictated by factors in addition to profitability (Arrow, 1969, p. 304). Thus informational channels, which typically have fewer other purposes to serve, are more expensive. In particular, personal contacts across nations are obviously much less extensive than within nations. That explains the importance of national trajectories in communication and diffusion of knowledge. In amplification of the first principle, there is one special case of unreliability from the receiver's point of view that is particularly stressed by Arrow : the inability for the receiver to understand the message. Every piece of the information "can be regarded as transmitted in a code and can only be used if decoded" (Arrow, Ibid.). In the first instance, a language itself is a code, and the sheer difficulty of translation perhaps can be underestimated. There are also problems in nonverbal forms of communication. More subtly, there are class and racial differences in the meaning of words, not so much in the literal denotation but in the connotations and associations, and in the significance of nonverbal behavior. In the complicated interplay of messages between teacher and student, the unreliabilities of communication can lead to extreme inefficiencies.

On the basis of these two principles, Arrow develops his theory of "Higher Education as a Filter" (1974a). As it is already noted, for Arrow, a channel has greater capacity if the receiver regards it as more reliable. That explains why the education has to be largely considered as a device to screen out abler persons for employers, and that, therefore, only a small part of earnings differentials by education can be attributed to the education per se. This position is explicitly contrary to the results achieved by Human Capital theory as well as to the assumptions of classical microeconomics. According to Gary S. Becker : "My own opinion is that schooling-as-screening must occur in a world with imperfect information, but is a relatively minor influence in determining earnings differentials by education" (Becker G., 1983, p. 6).

In fact, Becker rightly underlines the close relation between the hypothesis of "imperfect market information" and the theory of "schooling-as-screening". Less than a year before the publication of Arrow's article on "Higher Education as a Filter", Stiglitz advocated the theory of "screening" on the basis of his theory of market imperfection (Stiglitz, 1973). Arrow also acknowledges the relation between filter theory of education and the imperfect information and explores the historical background of such an explication , among others , in the writings of Herbert Simon : " The filter theory of education is part of a larger view about the nature of the economic system and its equilibrium . It is based on the assumption that economic agents have highly imperfect information . In particular , the purchaser of a worker's services has a very poor idea of his productivity . In this model , I assume instead that the buyer has very good statistical information but nothing more ...The general point that information in the real world is much more limited than that assumed in our usual equilibrium models has a long history among critics of the mainstream of economic thought . In recent years , it has been especially stressed by Herbert Simon and his followers . The particular emphasis on lack of information concerning the productivity of workers has been argued by me in the context of racial discrimination in employment ...and in a more general way, by A. Michael Spence in a recent Harvard dissertation..." (Arrow , 1974a , pp.52-53).

Furthermore, Arrow's theory of transmission relies on the relevance of personal contact in "coding" and "decoding" the information as signals. This emphasis on personal ties (that cannot be reduced to profitability considerations) undermines the fundamental assumption of classical microeconomic about the isolated individuals. Arrow's theory of transmission captures the interdependence among individual choices. One can influence the choice of his "friend" or "partner" and hence can formulate a strategic choice. In opposite to classical microeconomic, new microeconomic starts from Arrow's assumption of the interdependence among individual choices. Finally, national trajectories is one of the major explanatory factors of costs of transmission.

Summarizing our presentation of Arrow's theory of transmission, we propose the following causal chain :

(1) Information as a non-ordinary commodity → (2) Imperfect market for information → (3) Interdependence among individual choices → (4) Personal ties (networks) and national trajectories → (5) Coding and decoding signals → (6) Schooling-as- screening

IV) THE LIMITS OF ARROW'S THEORY

The originality of Arrow's theory with regard to the imperfection of the information market, and with regard to schooling as screening notwithstanding, his approach suffers from some serious pitfalls. We suggest a critical review of Arrow's theory in respect to the following four major topics:

1) **Codifiable Knowledge , Tacit Knowledge , and Mental Models** : Arrow treats learning as the progressive discovery of pre-existing 'blueprint' information, or Bayesian updating of subjective probability estimates in the light of incoming data. As G. Dosi (1988), G. Hodgson (1993-1994), and Nelson (1980) have argued, this is a very limited way of conceiving of the role of learning, which in reality is much more than a process of blueprint discovery or statistical correction. Learning is not simply the acquisition of codifiable knowledge. There is also **tacit knowledge**, as F. Hayek (1945), F. Knight (1933), M. Polanyi (1967), and many others have described. For instance, as it is argued by Knight, the tacit nature of entrepreneurial competence makes it non-communicable and non-contractible. Furthermore, problems do not themselves provide nor necessarily suggest solutions : much learning must involve intuition and creativity or "insight", as already remarked by Gestalt and other field theorists, and particularly by the proponents of evolutionary approach. (Dosi, 1991, p. 6 ; Hodgson, 1993-1994, p. 9).

Recent developments in cognitive science reveals the importance of mental models even in a single model of communication . Paul Churchland (1989) describes a simple model of communication for two agents in which the knowledge representation of the agents plays a key role in the communication . Agent L (for local) has made a decision inside her (his) mind , and wishes to explain the basis for the decision to her (his) supervisor , agent C (for center) . The patterns in L's mind must first be encoded in a language , such as English . This encoding would be perfect if there were a known set of dimensions in which to measure the factors that used L to make the choice she did , and if she could state her measurements of each of these

dimensions . This would constitute sufficient statistics for the decision , and communicating this data would be a perfect substitute for the neural patterns in L's mind . But the problem is that we almost never know what factors actually influenced a decision we have made . Much of our understanding in a choice situation can be **tacit** knowledge . We perceive things which we are not even consciously aware of , but which can affect a decision . Attempts to determine the factors and their weights can be made , but the basic problem is that we are always uncertain as to the dimensions of the knowledge space that must be measured . As a result , the encoding is almost certainly to be imperfect , and not all the information used by L to make the decision can be placed in the communication channel . The communication channel itself may be noisy and imperfect , and this problem has been studied extensively . This problem is a purely technical one and is not the cause of problems on which we wish to focus here . Instead , the decoding process at the listener , C , causes the next important communication problem . The listener must transform the message in the communication channel into changes in the neural patterns in her mind . The decoding is affected by the pre-existing patterns already in the listener's mind . The reception of a message and its interpretation by the listener are strongly influenced by the categories and beliefs that the listener already has about the world . To the extent that the speaker and a listener have common features in their mental models for the concepts identified in the shared mental model , they are more likely to be able to encode and decode their internal ideas into a shared language , and more likely to be able to effectively communicate using single terms to stand for substantial pieces of implicit analysis embodied in the shared mental model .

Mental models are shared by communication , and communication allows the creation of ideologies and institutions in a co-evolutionary process . The creation of ideologies and institutions is important for economic performance (North D. 1990) , as there exist gains from trade and production that require coordination . As various authors have written (Favereau O. , 1995 ; Orléan A. , 1994 ; North D. , 1990 , 1993 , 1994a , 1994b) , a market economy is based on the existence of a set of shared values such that trust can exist. According to North , " The morality of a business person is a crucial tangible asset of a market economy , and its nonexistence substantially raises transaction costs . LaCroix (1989) develops a model in which this intangible asset becomes a group-specific asset for a homogenous middleman group (such as Jewish , Indian or Chiniese traders in a society in which they are a minority) . A small group that maintains itself differentiated from the rest of society can enjoy much lower transaction costs than could two randomly chosen members of the society . " (North D. , 1994a , p.20).

Mental models , institutions and ideologies all contribute to the process by which human beings interpret and order the environment . What lacks in Arrow's theory of knowledge , is that it

does not take into board the **framed and tacit** knowledge , or mental models and their changes . In one of his very recent contributions , Arrow acknowledges the Hayekian's distinction between " scientific knowledge " and " tacit knowledge " (Arrow , 1994 , p.6) . Arrow calls scientific knowledge and the more transmittable parts of technological knowledge together as " reproducible knowledge ". He writes : " In many ways , the distinction between reproducible and tacit knowledge is parallel to that between evolutionary and conscious changes in social organisation . " However , he does not analyze the implications of the introduction of such concepts as tacit knowledge , or evolutionary changes in his model of rational learning and general equilibrium . Furthermore , in treating the " technological knowledge " , he neglects all the contributions of Michel Polanyi , as well as those of Nelson and Winter with regard to the tacit part of this type of knowledge , and the **routine** character of capabilities . By so doing , he implicitly admits that the analysis of tacit knowledge , evolutionary changes , institutions , ideologies and routines , i.e. , what creat human beings history , does not belong to the domain of general equilibrium .

2) **Rationality and Learning** : The agents in Arrow's model remain rational and learning is defined as "the acquisition of knowledge" (Arrow, 1962b, p. 158). In other words, for Arrow, learning is essentially a "rational learning" which occurs in the framework of the equilibrium analysis. The question which arises is how can agents be said to be rational at a given moment when they are in the process of learning? The very act of learning means that not all information is possessed and global rationality is ruled out. Artificial, probabilistic waverings to a model of an otherwise globally rational process of decision making do not provide an adequate remedy. Yet learning is more than the acquisition of information. It is the development of the modes and means of calculation and assessment, or as Hodgson remarks it is a kind of "representation" of reality, and thus, a "framed" knowledge (Hodgson, 1988, pp. 5-6). If the methods and criteria of "optimization" are themselves being learned how can learning itself be optimal? By its nature, learning means creativity and the potential disruption of equilibrium. The phenomenon of learning is antagonistic to the concepts of rational optimization and equilibrium.

Learning is not simply the acquisition of knowledge , but also changes in mental models . Once mental models are reduced to " codifiable knowledge " , the usual modeling of learning in economics would involve Bayesian ideas . The Bayesian learner starts out with some sort of prior distribution of beliefs over some pre-defined model space involving the learner's current ideas about how to think about the phenomenon that is the object of the learning . The prior beliefs are updated by some direct learning which generates observational data . This transition of prior beliefs into posterior beliefs with an unchanging model space is usually thought of as a gradual process with the posterior beliefs some sort of compromise between the peak of the

prior beliefs and the model judged most likely by the data alone (Leamer , 1987) . In other words , the Bayesian approach implicitly assumes that the dimensions of the internal mental models used to represent the external world are correct in some sense (see also Kalai E. , and Lehrer E. , 1990) . The connectionist approach (Hutchins E. , and Hazlehurst B. , 1992) and the classification models used by Holland et al. (1986) instead assume that the fundamental issue is to determine the relevant dimensions of reality for one's decision or learning purposes . For the learner , these dimensions are identified in large part by the existing shared mental models . A set of prior beliefs about action-outcome mappings is being learned as part of the shared mental model , whether traditional culture or ideology . Contrary to the Bayesian learner who is never surprised , or forced within the updating process to completely change the dimensions of the model space , connectionist approach admits such surprises . Surprises or drastically revised models can be interpreted as the change in mental models or in our " framed " or " representational " knowledge of the reality . This involves trajectories which can be described as punctuated equilibria of the sort analyzed in Denzau and Grossman (1993) , Denzau and North (1994a) , and in the litterature concerning technical change in the United States (see Nelson R. 1994). " Punctuated equilibrium involves long periods of slow , gradual change punctuated by relatively short periods of dramatic changes , which we can presume to be periods of representational redescription " (Danzau and North , 1994a , p.23) . The authors of the connectionist approach have illustrated the patterns of learning . According to Hutchins and Hazlehurst , both direct learning and the culturally mediated learning show patterns of punctuation (figures 7 , 10 , and 11 in Hutchins and Hazlehurst) . The punctuated equilibrium approach underlines the evolutionary process of changes in the meaning of words , concepts and the bringing of new meanings from related mental models , by analogy or metaphor . Hence , this approach tries to capture the role of novelty , surprise , institutions and radical shifts in the dimensions of the model space of our " representations " or " framed " knowledge . Learning as a change in mental model cannot be captured by Arrow's model of learning . New approaches , such as the connectionist and the punctuated equilibrium ones are more promising.

3) **Parametric Uncertainty and Structural Uncertainty**: Future knowledge is by its nature unknown and the results of research and development are uncertain in the most radical sense. This insurmountable difficulty in the specification of outcomes means that it is unlikely that developed futures markets for innovations and knowledge could ever exist. Prediction of specific events in a complex and uncertain world is severely constrained and generally analytically irreducible to probabilistic risk or parametric uncertainty. The existence of structural uncertainty in these and other areas means that "the future is not reducible to the present- for instance by means of probabilities" (Hodgson G., 1993-94, p. 10). For this reason, markets cannot cope adequately with technological development and they often

eschew uncertainties. Of course, in the case of "learning-by-doing", it is possible to express learning by a systematic shift in the firm's production function. However, the innovation cannot be reduced to "learning-by-doing" (Morishima M., 1992, p. 6). While "learning-by-doing" mainly involves a parametric uncertainty, innovation bears radical or structural uncertainty.

4) **Individualistic Conception of Knowledge** : Whilst Smith recognized the benefits of the division of labor through some enhancement of skills ("learning-by-doing"), what is missing in his writings is an idea of corporate culture and the organization's role in the generation, transmission and protection of practical knowledge. Marx, however, considered the modern capitalist factory as "the power of collective worker" appropriated by the capital against the individual alienated worker (Capital, Vol.I, 1978, p. 281). Instead, Smith writes of "the increase of dexterity in every particular workman". This individualistic concepts of knowledge is also present in the Arrow's theory. That the knowledge within a corporation relates essentially to the organization and the group, rather than to the individuals composing them, is significantly emphasized by Sidney Winter. He writes : "The coordination displayed in the performance of organizational routines is, like that displayed in the exercise of individual skills, the fruit of practice. What requires emphasis is that... the learning experience is a shared experience of organization members... Thus, even if the contents of the organizational memory are stored only in the form of memory traces in the memories of individual members, it is still an organizational knowledge in the sense that the fragment stored by each individual member is not fully meaningful or effective except in the context provided by the fragments stored by other members." (Winter, 1982, p. 76)

Since learning and communication of employees take place only within the organizational framework, "their knowledge, as well as their capacities to communicate with each other are not individually portable" (Winter, 1982, p. 45). Contrary to the view of information and knowledge as portable, knowledge is embedded in social structures. This is partly because learning is an "instituted process of interpretation, appraisal, trial, feedback, and evaluation, involving socially-transmitted cognitive forms and routinized group practices" (Hodgson, 1993-1994, p. 14).

Winter's argument about the group nature of much organizational knowledge suggests that although tacit or other knowledge must reside in the nerve or brain cells of a set of human beings, its enactment depends crucially on the existence of a structured context in which individuals interact with each other. Otherwise, no such knowledge can become operational. Furthermore, because organizational knowledge is tacit knowledge, by definition it cannot be expressed in a codified form. The knowledge becomes manifest only through the interactive

practice of the members of the group. It is both learned and transmitted in a group context only.

Arrow also contends that : " social variables , not attached to particular individuals , are essential in studying the economy or any other social system and that , in particular , knowledge and technical information have an irremovably social component , of increasing importance over time . " (Arrow , 1994 , p.8) . The " social component " of knowledge notwithstanding , Arrow maintains that " methodological individualism " and " rational behavior " must not be neglected in treating " social knowledge " , communication networks and organizational designs.

Since an organization , by definition , is composed of a multiplicity of individuals , there are necessarily at least two places for rationality to enter the discussion . One is at the individual level . Given an organization and its rules of operation , including rewards and punishements , one may want to assume that individuals behave rationally and to examine the implications of that assumption . For Arrow , " rationally " , in this cotext , " is taken to be individualistically rational . Individuals are assumed to maximise a utility function based on their own consumption , including that in the future and under uncertainty , under constraints imposed by organizational rules and incentives " (Arrow , 1991 , p.2).

Typically this assumption of rationality among the individuals within an organization , whom we call its **agents** , is accompanied by a more or less formal attempt to choose the operating rules of the organization so as to achieve some specified goal , for instance maximizing expected discounted profits , or minimizing the governance costs . According to Arrow , " sometimes this is done in a highly formal manner , as in the research area now known as ' principal-agent theory '. Sometimes it is done less formally and with closer attention to institutional detail , as in the work of Williamson ... in which both the ability of individuals to profit from the operating rules and the possibility of designing organizational rules to motivate individual self-seeking to the benefit of the organization's aims are explored" (Arrow, 1991, p.2).

There is another tradition , which ignores individual incentives . It is called " team theory " as set forth in **The Economic Theory of Teams** (Marschak and Radner , 1972) . The goal of this theory is to be able to compare alternative designs by a two-step method . First , for each given design , we find the optimal mode of functioning for the organization . Second , the cost of operating the communication process is to be subtracted from the optimized objective function of each design , and their net values compared . **The Economic Theory of Teams** did not actually carry out this program . As Green and Laffont have noted , team theory , " did set

up some useful definitions , and it provided some important results on the first of these steps . But the second step , cost assessment and comparison , was not really attempted , despite a clear view of the problem" (Green and Laffont , 1986b , p.256). In Arrow's viewpoint, the difference between " team theory " in one hand and " principal-agent theory " and "transaction cost theory" on the other hand is not sharp. However, "in practical development, it is easier to study the implications of complex informational structures in the team context, simply because we can bypass the difficulty created by incentive compatibility constraints, which are generally difficult to handle." (Arrow, 1991, p.3). Relying on a team approach, Arrow tries to show that the possibility that elite control is connected with economies of scale in the process by which information is communicated. Hence, it will pay to reduce the number of individuals among whom information is to be communicated and have each transmit more.

Undoubtedly, Arrow's theory of scale returns in communication is a brilliant idea which calls for new models of "optimal communication", since standard models usually lead to what amounts to diminishing returns, in which case there will be no gains in excluding a large number of individuals from the process. It is noteworthy that even Green and Laffont (1986), who set forth in their model of alternative limited communication systems, the task of removing the main pitfall of "team theory", namely cost assessment and comparison of different information structures, assume that "the costs of coding and decoding are identical and **do not involve increasing returns**." (Green and Laffont, 1986b, p.256, underlined by us). This assumption is well in the tradition of team theory. As stressed by Arrow (1982) : "team theory assumes a fixed amount of communication in fixed channels. The costs of communication are modelled by scarcity." Diminishing or non-increasing returns in communication costs is the common assumption of many standard models, including team theory.

Actually, natural models for communication costs are derived from statiscal theory. One approach is to analogize a message to a random sample. Suppose one is seeking to estimate a random variable X. One is permitted to take a sample of n observations, each of which is an observation of X with a random error u normally distributed with mean 0. If successive errors are independent, then from a Bayesian viewpoint the variance of the best posterior estimation of X is a decreasing function of 1/n. More specifically , if we define the **precision** of an estimate as the reciprocal of its variance , then precision is a linear function of n. Precision is clearly a measure of information in a decision problem. If we assume that the cost is proportional to n, then we can infer that the cost of information is linear in precision (viz the marginal cost of precision is a constant). On the other hand, the extent to which the decision falls short of the best possible if the true value of X were known might reasonably depend on the variance (namely,the reciprocal of the precision). Hence the marginal benefit from

precision is decreasing. Thus, if we think of the cost of communication as linear in the precision of the message, we can find an optimal level of communication.The choice of optimal level is a well-behaved problem in that the benefit function is a concave and the cost function linear.The well-known Shannon measure of information has several interpretations ; one of them is a cost measure-the cost of finding the correct item among a class when the probability that each one is the correct item is known-and the search procedure consists of successive dichotomies of the class to test in which subclass the correct item is.

This interpretation is particularly applicable to messages, where each successive symbol amounts to identifying a subclass of possible messages among the set defined by the preceeding symbols.This is an alternative to precision as a measure of information, with advantages and disadvantages ; but again it typically gives rise to well-behaved decision choices. The picture that emerges from these two models is that of successively decreasing benefits to communication. Whereas according to Arrow, "a message has a syntactic and narrative structure. A small part of the message conveys virtually nothing useful. The communication theory picture, in which the first symbols restricts the field of possibilities, the second restricts it further, and so on, is of course formally correct. However, in terms of use value, the opening symbols may tell us virtually nothing useful. It is not for nothing that, in the messages conveyed by accounting, the interesting part is the "bottom line". In short, it would appear that **we have increasing returns** to the length of the message. This is of course a very imprecise statement, for the very definition of returns to scale implies that we have numerical measures of input and output. At the present time, this statement must be regarded...as a statement that the optimal joint choice of communication channels and decision rules based on them is a **non concave problem**... For example, zero communication may be better than a little bit" (Arrow,1991,p.5). The emphasis on the syntactic and narrative structure of message for concluding the scale returns in communication is undoubtedly a great revolution inside the individualistic and static analytical framework of team theory. However, it is yet far from an interactive and dynamic vision of communication channels, and dynamic organizations (for a Saussurian interpretation of interactive relation, see Nooteboom B. ,1992).

Formulated in the seventies, team theory makes in fact the second stage in the economics of information centered on comparing communication networks. In the first stage, the issue was the design and evaluation of communication processes. The economy was depicted as continually changing. A good system of communication was one that could quickly and accurately disseminate information about its current state. Writers such as von Hayek (1945) wanted to evaluate the price system in this informational role. Emphasis was primarily on the continued **flow of new information**, and on the transitory character of the state of the economy. Whereas the theory of teams dropped the concepts of information flow about a

continually changing state in favor of a more static view, with the exception of chapter 7 in Marshack and Radner (1972) which was later developed by the agency school. As Green and Laffont correctly observe : "The state of the system was fixed, and team members each possessed different information about it. This was in the tradition of statistical decision theory, where one regards the parameters of a distribution as unknown, and seeks optimal responses to the available information...Marshak and Radner tried to study the question of optimal communication structure within the team. However, it is fair to say that most of their results concern the characterization of the optimal decision rule for a fixed communication structure, rather than this comparison." (Green and Laffont, 1986a, p.240).

The third stage begins with the contributions of agency theorists and transaction cost economics in the second half of the seventies and during the eighties.The major part of studies in this stage has been consacrated to the comparison of organisational designs and communication channels in their static states.Comparative statics, and not a dynamic analysis, was developed.These studies involved the explicit introduction of differences in objectives among the agents. Communication problems of a technplogical nature were largely ignored. Instead, most attention was directed at the problem of providing the incentives necessary to make the self-interested agents divulge their information. The idea of a communication network was no longer pursued.

To recapitulate this development, we have seen that the ideas of information as a flow and of communication as a comlex network design problem have been replaced by a static view of the system and a costless technology for information transmission. The contributions of the third stage tried to reintroduce the idea of information as a flow to study the interaction of communication constraints and incentives question. However many problems remain unresolved and call for a fourth stage in economics of information in order to capture the dynamics of organizations, institutions, and culture through time. For instance, the analysis of information as a flow through time brings us to the study of learning in general and collective learning or culture in particular. Furthermore, a more profound treatement of incentive structure shows that it is determined by institutional environment and arrangements of a society. As North correctly points out : "Incentives embodied in belief systems as expressed in institutions determine economic performance through time, and however we wish to define economic performance the historical record is clear" (North D.,1994b,p.364).

Despite his influential discovery of scale returns to communication, Arrow's analysis of communication channels and organization designs suffers from two serious shortcomings : (1)it is static and does not consider the information as a flow (2)it neglects not only the incentive structure but also institutions. Occasionally, Arrow refers to culture as some kind of

"information" or "constraint" that causes the individual to act one way rather than another. Whereas culture is not simply information affecting individuals. It consists not merely of beliefs and assumptions, but also behavior patterns, habits, language and signs, even rituals and patterns of behavior. Moreover, the kind of "information" that is used and transmitted in a culture is embedded in social structures and organizations, in the sense that its existence and transmission depend upon them. Even the kind of information held by a single individual is typically context dependent ; information and structure are mutually interwined (Hodgson G. ,1993, p.253). It is thus difficult to locate culture in individuals. Culture and institutions transcend the individuals to whom they relate. By seeing culture as a structured and interactive belief-action system its collective quality can be appreciated.

CONCLUSION

Economics of information owe much to Alfred Marshall rather than Léon Walras. It was Marshall who considered information, particularly technical knowledge as a prime example of what we have come to call externalities. Roughly speaking, these are social interactions not mediated through the market. Arrow's description of information as a specific non-ordinary commodity, revealing the limits or imperfections of market and entering into the general category of "externalities" is rooted in the Marshallian tradition. This means also that Arrow in his discussion of knowledge and information as social as well as individual characteristics remains wholeheartedly faithful to methodological individualism of standard economic theory. Arrow set forth some fundamental principles of the economics of information and the new microeconomics by focussing on issues such as information gathering, communication efficiency, and transmission costs in deciding among forms of economic organisation. Arrow's model of learning-by-doing, his subtle observation of scale returns to communication, his analysis of education as sorting and screening, his treatement of the relationships between the competitive allocation mechanism and other planning procedures and their corresponding advantages and disadvantages with regard to the centralization of information are among the major contributions which permitted a systematic scientific treatement of economics of information. One reason for the rapid acceleration of this type of economic theory is the wide applicability it has found in other areas of economics. Problems of optimal taxation, sorting and screening, adverse selection in insurance, employment contracting, the theory of auctions, among others, have all been shown to be special cases of the general information transmission problem. However, there is another reason which in our opinion guarantees its increasing importance during the coming decades.

Describing the new features of capitalism since the late sixties, many authors have suggested a variety of titles, such as post-industrial society, late capitalism, multi-national corporations

capitalism, monopoly-state capitalism, etc. In some respects, I prefer to call this new capitalism as information capitalism, in order to underline the collective force of scientific knowledge being applied as directly as ever to production by the aid of third technological revolution in electronics and computer science. Information capitalism depends not on the regimentation of labor into a commodity; instead it depends on a new ability to transmit and transform information,and to connect people and ideas in new ways. The new product of this information capitalism is the complex merchandises and productive networks which comprise many interconnected processes of production and service, among them data marketing business and the internet (see "Year of the Internet", **Newsweek,** Dec. 25, 1995 / Jan.1, 1996). There are more and more examples of firms whose primary value is the possession of an informational advantage. The private property essential to the firm is eroded by the public access to the information which is part of that property. Arrow's statement concerning the "inappropriability" of information shows its practical relevance in this context. Since we are going to see new forms of property with aspects of both private and public goods related to this information capitalism.The difficulty to precise the "intellectual property" as included in the last Uruguay Round of G.A.T.T. is one of the first signals of the importance of the new forms of property in international commerce. Externalities, of course, cover many things as diverse as environmental issues, air and water pollution, global warning, toxic wastes, as well as information. However information as "externalities" in an epoch of information capitalism implies a radical change in institutions, particularly in the property rights. In the whole history of capitalism, it was never so difficult to demarcate a division line between "private" and "public" as it is in the era of information capitalism.

Given the significance and dimension of the problem, it is questionable whether the "externalities" is an appropriate concept to explain information or non-market social interactions in general. More generally, the great challenge for neoclassical paradigms is whether its methodological individualism is capable to come to grips with the collective or social nature of information.New knowledge is acquired in two different ways : (1) acquisition from observing nature (2) learning from other individuals. As Arrow correctly remarks it is indeed the first of these two modes of information acquisition that fits well into the individualistic paradigms (Arrow K., 1994, p.8) . However, the second mode, viz learning from others present many pecularities that do not match with neoclassical paradigms. The subtle observation of Arrow regarding the increasing returns to communication is one of those pecularities which contradicts the scarcity of information. Bounded rationality is another example. As far as bounded rationality refers to the limited capacity of individuals to collect and treat information, it can be accepted by individualistic paradigm. However, whenever it consists of "framed" knowledge, tacit and routinized knowledge, or culture as a structured and interactive belief-action system the individualistic approach is not so promising. Institutions,

rather than individuals, are perhaps a better beginning for the appraisal of social nature of information, its context dependence, and its flow through time.

In our critical review of Arrow's theory of information, we tried to show that despite its great achievements, this theory lacks the tacit, institutionalized, unexpected and non-rational dimensions of knowledge. The organizational or corporate culture cannot be derived from market failure or market imperfection. It is the direct outcome of internal organization of firm and other social networks, and thus closely related to learned and transmitted knowledge in a group context. Hence knowledge does not simply reflect the **limits of market** (as suggested by Arrow, 1974), and the presence of parametrical uncertainty[5], it implies the **power of organization** and networks in the face of radical uncertainty.

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[5] It should be noted that G. Debreu's position on uncertainty is the same as Arrow's position: "By a simple reinterpretation of the concept of a commodity, the classical economic theories of equilibrium and optimality can be extended, without change of form, to the case where uncertain events determine the consumption sets, the production sets, and the resources of the economy." (G. Debreu, 1989, p. 115).

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