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The neo-Schumpeterian approach to innovation and Keynes's probability: initial explorations

A abordagem neo-schumpeteriana da inovação e a probabilidade de Keynes: explorações iniciais

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RESUMO: O objetivo do artigo é mostrar que o conceito de probabilidade de Keynes pode enriquecer a compreensão do processo de introdução da inovação oferecido pela abordagem neo-schumpeteriana. Para lidar com a incerteza, os neo-schumpeterianos introduzem o conceito de rotinas. O que é sugerido aqui é que os conceitos de Grau de Crença Racional e Peso de Argumento, que vêm da teoria da probabilidade de Keynes, quando usados em conjunto com o conceito de rotinas, ajudam a entender a racionalidade do processo de tomada de decisão na introdução de uma inovação.
PALAVRAS-CHAVE: Análise neo-schumpeteriana; incerteza; inovação; probabilidade.

ABSTRACT:The aim of the paper is to show that Keynes's concept of probability can enrich the understanding of the process of the introduction of innovation offered by the Neo-Schumpeterian approach. To deal with uncertainty Neo-Schumpeterians introduce the concept of routines. What is suggested here is that the concepts of Degree of Rational Belief and Weight of Argument, which come from the Keynes theory of probability, when used together with the concept of routines, help understand the rationality of the decision-making process in introduction of an innovation.
KEYWORDS: Neo-Schumpeterian analysis; uncertainty; innovation; probability.
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I. INTRODUCTION

The aim of this paper is to show that Keynes's concept of probability can enrich the understanding of the process of the introduction of innovation offered by

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the Neo-Schumpeterian approach. The latter has a peculiar understanding of the technical change process, which includes concepts such as knowledge base, cumulativeness, technological paradigm, technological trajectory, and uncertainty. To deal with this uncertainty Neo-Schumpeterians introduce the concept of routines. What is suggested here is that the concepts of *Degree of Rational Belief* and *Weight of Argument,* which come from the Keynes theory of probability, when used together with the concept of routines, can clarify the rationality of the decision-making process in introduction of an innovation. In section II, we describe those aspects of the Neo-Schumpeterian (hereafter NS) approach to technology that are important for our discussion. The main features of Keynes's probability are presented in section III. Its possible links to the NS approach are discussed in section IV and a model combining these aspects of the two approaches is suggested. Section V is the conclusion with suggestions for further development.

II. THE NEO-SCHUMPETERIAN APPROACH TO INNOVATION

Until the second half of the 70s the majority of the economic literature relating to technical change was divided into two groups according to their understanding of the nature of an innovation: the so-called demand pull and technology push approaches. The basic difference between them depends on what is viewed as the main source of innovation: the former attributes to market mechanisms the unique determinant of technical change and the latter postulates the state of science as the main source of innovation.[1] However, after this period a number of authors (Rosenberg, 1976; Nelson & Winter, 1977, among others), started to argue that an intermediate approach could be found. In other words, they believe that neither the demand pull nor the technology push approach can alone provide the elements for the full comprehension of the technological change process. This group will be named here Neo-Schumpeterian, as they find in Schumpeter's writings the inspiration for their analyses.[2] For the NS,

> "Technology – far from being a freed good – is characterised by varying degrees of *appropriability,* of *uncertainty* about the technical and *a fortiori,* commercial outcomes of innovative efforts, of *opportunity* for achieving technical advance, of *cumulativeness* in the patterns of innovation and exploitation of technological know-how and hardware, and of *tacitness* of the knowledge and expertise on which innovative activities are based." (Silverberg, Dosi & Orgenigo, 1988, p. 1032)

[1] For a review about the critics to these approaches see Dosi (1982).

[2] This group is also called evolutionary. However, as these labels have been used to classify theoretical approaches which cover more than technological aspects of the economic system, we prefer to use the label Neo-Schumpeterian as the main concern of the essay is technical change.

To understand this concept of technical change it is important to comprehend two essential features of the innovative activity: *knowledge base* and *uncertainty.*

Knowledge Base

Knowledge base is related to the characteristics of the knowledge used in an innovation. According to Dosi (1988b, p. 224), various sorts of pieces of not mutually exclusive knowledge are used in the solution of most technological problems: universal versus specific; articulated versus tacit; public versus private.

Universal knowledge means that knowledge that has a large applicable understanding, which is based on principles that are well known and pervasive, while specific knowledge means a special "way of doing things". Moreover, there are some sorts of knowledge that are well articulated and for the most part is written down in manuals, books and so on. In contrast, there is also that kind of knowledge that is tacit, meaning that it comes from experience and practice. Important processes of acquisition of tacit knowledge are "learning-by-doing" and "learning-by-using". The latter implies that this knowledge is not a public good to be freely and easily adopted by all potential users, but the cost of exploiting and developing new or borrowed technology depends on the availability of technical and social capabilities.[3] Finally, there is that knowledge that is public in the sense that it is available in scientific and technical publications. On the opposite side, there is that knowledge that is private either because it is protected by law (patents) and/or because it is tacit.

Knowledge base is "the set of information inputs, knowledge, and capabilities that inventors draw on when looking for innovative solutions" (Dosi, 1988a, p. 1126). The kind of knowledge used in some innovative activity will define the knowledge base of that activity. Obviously, different activities (sectors) will determine different knowledge bases and, thus, the importance of each kind of knowledge discussed above will differ. This explains why the organization of research activities and the characteristics of the innovative activity vary across sectors, and moreover explains why different industrial sectors have varying degrees of appropriability of the benefits of the introduction of innovation. Moreover, even within one specific sector the knowledge used by firms will differ. As pointed out by Dosi & Orsenigo (1988, p. 16), technology

> "[...] involves specific, often idiosyncratic, partly appropriable knowledge which is accumulated over time through equally specific learning processes, whose directions partly depend on firm-specific knowledge and on the technologies already in use."

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The concept of knowledge base and its implications can be better understood with the help of two important contributions made by the NS, that is: the concepts of technological paradigm and technological trajectory. As an analogy to Kuhn's (Kuhn, 1962) concept of scientific paradigm, Dosi (1982, p. 152) defines a technological paradigm (hereafter TP) as a

> "[...] 'model' and 'a pattern' of solution of selected technological problems, based on selected principles derived from the natural sciences and on selected material technologies."

Examples of TP include the internal combustion engine, oil-based synthetic chemistry, and semiconductors.[4]

The concept of TP implies a set of heuristics – e.g., where do we go from here? Where should we search? What sort of knowledge should we draw on? (cf. Dosi, 1988a, p. 1127) – and a prescription of *directions* of technical change to pursue and those to neglect. What is important here is that the innovative activity is not a random process, where for each new innovation the investor is free to look for any specific direction. The innovator is always constrained by the TP in which he/she is grounded. As there are different TPs, each technology has its specific procedures, competences and heuristics.

Dosi (1988a, p. 1128) argues that after the emergence of a new TP,

> "It quite often happens that prototypical problem-solving models, rues on how to search and on what targets to focus, and beliefs as to "what the market wants" become the shared view of the engineering community."

Thus, at any moment in time, there is always a TP that determines the features of the innovative activity for every sector of the economy, imposing a selective, precise and ordered pattern of technological change.

In this context, the technological trajectory (hereafter TT) is "the activity of technological process along the economic and technological trade-offs defined by a paradigm" (Dosi, 1988a, p. 1128 and 1988b p. 225). This concept has a direct relationship with the concept of progress. In Dosi's words (1982, p. 154):

> "The *normal* problem solving activity determined by a paradigm can be represented by the movement of multi-dimensional trade-offs among the technological variables which the paradigm defines as relevant. Progress can be defined as the improvement of these trade-offs."

Technological Trajectories have six important features:

(i) They might be more powerful (circumscribed) or less powerful. The

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[4] It is worth noting that the technological paradigm is very similar in concept to the technological regime (Nelson &Winter, 1977), technological guidepost (Sahal, 1981), and focusing devices (Rosenberg, 1976).

powerfulness of the trajectory is defined according to the size of the set of technologies which it excludes.

(ii) There can be complementarities among trajectories. The path of development of one trajectory might have an effect on the path of development of another trajectory.

(iii) There is a technological frontier, which means the highest level that can be achieved using the trade-off between technology and economic dimensions. This highest level is itself defined by the TP.

(iv) Progress along the trajectory is *cumulative*. The probability of new advances is related to the position that the innovator occupies vis-a-vis the technological frontier. The nearer the technological frontier, the greater the possibility of introducing a new innovation, and the greater the knowledge accumulated.

(v) The more powerful the trajectory, the more difficult it is to switch from one to other. The explanation for this is related to the fact that as one accumulates knowledge, one becomes locked into the trajectory. If one changes trajectory, one has to start from the beginning in the problem-solving activity.

(vi) *A priori* it is difficult to make judgements about the superiority of one trajectory over another. As Dosi (1982, p. 154) explains

> "[...] an unequivocal criterion can be easily identified only within a technological paradigm (i.e. along a technological trajectory). Comparison (even ex-post) between different trajectories might yield sometimes, although not always, to ambiguous results. In other words, it might occur that the 'new' technology is 'better' than the 'old' one in several chosen dimensions, but it might still be 'worse' in some others."

Three important implications arise from the conception of technical change shown above. First, it is very clear that technology is not a free good that one can pick up on the shelf. The concepts of knowledge base and cumulativeness show very clearly that the alternatives that an innovator is faced with are limited, meaning that the directions of the search activity are predetermined.

Second, it is the emergence of a new technological paradigm, rather than the market, which defines what the potential innovations are. This does not mean that the market mechanism has no role as an inducement to innovate. According to Dosi (1988a, p.1120),

> "In the most general terms, private profit-seeking agents will plausibly allocate resources to the exploration and development of new products and new techniques of production if they know, or believe in, the existence of some sort of yet unexploited scientific and technical opportunities; if they expect that there will be a market for their new products and

processes; and, finally, if they expect some economic benefit, net of the incurred costs, deriving from the innovations."

Thus, as the above quotation shows, the market does have a role in this process. But this role is constrained by the features of the TP. Inducement to improve the level of profits always exists in a business operation. As explained by Rosenberg (1976, p.110) however, since this incentive is so general, it does not explain either why a specific innovation is introduced or the timing of the introduction. Moreover, as some studies indicate (Soete & Dosi, 1983; David, 1975), the features of a new technology are generally superior to the old one so that, even if there is no change in the relative prices, the new technology could be adopted profitably. What has to be understood is that the market incentives *alone* cannot provide a clear understanding of the technical change process. However, some market incentives, "*coupled with the paradigm-bound, cumulative, and local nature of technological learning can* explain particular rates and directions of technological advance" (Dosi, 1988, p. 1143).

Finally, the concepts of TP and TT are a powerful instrument in the analysis of why innovative activity differs among sectors. It will be the features of the TP and the TT that will define the difference among the degrees of appropriability and levels of opportunities of technological advances.

Uncertainty

The second essential feature of the innovative activity, uncertainty, plays an important role in the understanding of technical change by the NS approach. According to Freeman (1974, pp. 223-7), there are three kinds of uncertainty that affect the innovative activity: business, technical and market uncertainties. The first one is related to environmental variables (political, economic, legal etc.) and affects all decisions related to the future. This is a kind of uncertainty that is not specific to the innovative activity, but to economic decisions as a role. The other two kinds of uncertainty are project specific. Technical uncertainty refers to realized standards of performance under various operating conditions for a given expenditure on R&D, while market uncertainty refers to the extent to which the innovation will be commercially successful for a given product specification (Kay, 1979, p. 18).

Despite the fact that these categories of uncertainty appear in every innovation, the degree varies according to the type of innovation. Freeman (1974, p. 226) shows that there is a qualitative difference between the uncertainty associated with a radical product innovation, which is of very high degree, and that related to the introduction of a product differentiation, which is of a much lower degree. This difference of uncertainty is related to the development of technological paradigm and technological trajectories, in a sense that they focus the direction of search and give better grounds for the formation of technological and market expectations (cf. Dosi, 1988 p. 1134).[5]

Notwithstanding these categories of uncertainty are related to different aspects of the innovative activity, they have the same basic sources. According to Dosi & Egidi (1991, p. 145) the sources of uncertainty are the fact that

> "incompleteness of the information set, which means the lack of all the information which would be necessary to make decisions with certain outcomes and knowledge incompleteness, which means the inability of the agents to recognize and interpret the relevant information (limitations on the computational and cognitive capabilities of the agents)."

When related to the introduction of an innovation, the first source *(incompleteness of the information set)* means that when someone starts to research a solution for a technological problem, he/she lacks some fundamental information, and this lack of information makes the innovative activity completely uncertain. This information might include, for example, the length of time that it will take for the innovation to be found; the cost of this innovation; and its acceptance by the market. One is therefore faced with strong substantive uncertainty, which means the impossibility, even in principle, of defining the probability distribution of future events (cf. Dosi & Egidi, 1991). Thus, the innovative activity is not an activity subject to risk but to *true uncertainty.*

The second source *(knowledge incompleteness)* is based on the concept of procedural uncertainty. There is here a clear distinction between knowledge and information. Access to the latter does not guarantee the acquisition of the former. The acquisition of knowledge lies in the ability to process the information. To deal with this uncertainty the agents develop a "rational behaviour", which implies the search for stable rules and procedures (routines), that give to the agent some security with which to face the uncertainty. These routines codify the procedures and knowledge involved in the solution of particular problem, and are conditioned by the technological paradigm.[6]

To sum up, the NS approach to technical change assumes that substantive and procedural uncertainties are essential features of the innovative activity and, in order to deal with this, routines are developed. These routines, in turn, are contingent on the competences and heuristics of the technological paradigm, which allows the emergence of the concepts of appropriability, opportunity and cumulativeness,

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[5] It is important to note that although it can be *reduced,* uncertainty is never *eliminated*. According to Dosi (1988, p. 1134), "Even when the fundamental knowledge base and the expected directions of advance are fairly well known, it is still often the case that one must first engage in exploratory research, development, and design before knowing what the outcome will be [...] and what some manageable results will cost, or, indeed, whether very useful results will emerge" (Mansfield et al., 1977).

[6] The concept of path-dependency is very useful in grasping why these routines are conditioned by the technological paradigm. For a discussion of this point, see David (1985) and Rosenberg (1994).

making the understanding of the technical change unique. Moreover, it was shown that uncertainty varies according to different types of innovation, decreasing from a situation in which there is a high degree of uncertainty – usually in research activities – to situations with a low degree of uncertainty – development activities. As pointed out before, routines as defined by the technological paradigm and technological trajectories reduce but do not eliminate the uncertainty. They are fundamental in a problem-solving activity since they help in

> "[...] the identification of relevant information, the application of pre-existing competences or the development of new ones to the problem solution and, finally the identification of the alternative courses of action." (Dosi & Egidi, 1991, p. 150)

However, the last act of a problem-solving activity (choice) under uncertainty remains to be made. After following the routines related to a specific kind of decision, which course of action should be taken? Concerning to the introduction of an innovation, what makes an investor decide between the immediate introduction of the innovation or a delay? To answer these questions, we think that the use of Keynes's theory probability can be helpful, as it is related to the decision-making process under uncertainty.

III. KEYNES'S PROBABILITY

Since the beginning of the 80s, Keynes's vision of probability has been under debate, mainly by the post-Keynesians (Carabelli, 1985, 1988, 1992 and 1995; O'Donnell, 1989, 1990, 1991; Lawson, 1985, 1988, among others). For the present we will only discuss that aspects that are related to our discussion.

For Keynes, probability is about logical relations between sets of propositions, premises and conclusions. In Keynes's words,

> "Let our premises consist of any set of propositions *h,* and our conclusion consist of any set of propositions *a,* then, if a knowledge of *h* justifies a rational belief in *a* of a degree a., we say that there is a probability relation of degree a. between *a* and *h*. This will be written $a/h = \alpha$." (Keynes, 1973a, p. 4 and n1)

As one can see from the quotation above, Keynes's " probability was embodied in arguments and judgements which had no direct relationship with empirical and physical entities and which referred to the process of reasoning, rather than to the happening of events" (Carabelli, 1988, p. 15). It is clear that Keynes identifies "degree of partial entailment" with "degree of rational belief" (cf. O'Donnell, 1989, p. 35 and O'Donnell, 1990, p. 254), which means the degree to which *a* follows *h*. The probability relation or the degree a of rational belief ranges from a situation of certainty $(a/h = 1)$ to a situation where it is impossible to establish a rational belief that *a* follows from *h* ($a/h = 0$). A situation where $0 \leq a/h \leq 1$, means that it is possible to assume degrees of certainty (cf. O'Donnell, 1989, pp. 35-6).

However, it is important to note that what is described here as certainty does not mean truth. Truth is a property of propositions, while certainty is a logical relation between propositions. When the situation of $a/h = 1$ occurs, this means that a logical relation between two propositions allows someone to believe that *a* follows from *h* with certainty.

An illustration can help understand Keynes's probability. Suppose that someone has just arrived at earth, and he/she has no *a priori* knowledge about the human race. This alien meets 10 human beings, all of them white. After that he/she is informed that there is another human being, Peter, and he/she will meet him later. According to his/her knowledge about the human race, he/she concludes that Peter is white with certainty. In Keynes's probability framework this situation can be represented as follows. The alien's set of premises is "Peter is human" and "All humans are white" *(h)* and his/her conclusion *(a)* is "Peter is white". A logical probability relation of the type $a/h = 1$ can be established. In other words, he/she argues that "Peter is white" with certainty as he/she knows that "Peter is human" and "All humans are white". Certainty in this case does not mean truth, but only that one can believe in *a* with certainty for this conclusion follows from the premises (knowledge) one has.

On the other hand, suppose now that the set of knowledge accumulated by the alien is the following: *h* = "Peter is human" and "All humans are mortal". So, a conclusion like *a*= "Peter is immortal" is impossible. In this case we have $a/h=0$, meaning that the knowledge of *h* makes *a* impossible, or false.

Finally, there are those situations where neither a certainty nor an impossibility can be established. Suppose now that the premises are: *h* = "Peter is human" and "The majority of human beings have more than 1.70m in height". Based on this premises the alien can have a Degree of Rational Belief (DRF) that "Peter is higher than 1.70 m" (a). So, $0 < a/h < 1$.

The examples above illustrate some properties of Keynes's probability that are worth discussing. First, probability is an attribute of propositions and not of things in themselves;

> "No proposition is itself either probable or improbable, just as no place can be intrinsically distant; and the probability of the same statement varies with the evidence presented, which is, as it were, its origin of reference." (Keynes, 1973a, p.7)

Secondly, as probabilities are connected to logic and not to psychology, they are never subjective, but always objective as associated with knowledge (Lawson, 1988):

> "But in the sense important to logic, probability is not subjective. It is not, that is to say, subject to human caprice. A proposition is not probable because we think it so. When once the facts are given which determine

our knowledge, what is probable or improbable in this circumstance has been fixed objectively, and is independent of our opinion. ‘’ (Keynes, CW, vol. VIII, p. 4)

So, despite the fact that for the same sets of premises h and conclusions a, different individuals may have a different probability relation, the way that these probabilities are determined is completely objective.

Thirdly, following from the second property, probability is always concerned with rational belief, and not with mere belief or psychological belief (cf. O’Donnell, 1989, p. 37).

Fourthly, for Keynes, his conception of probability has a universal application.

> “His theory of rational inference thus takes the whole of human thought as its domain, ranging across areas as diverse as actuarial studies, legal disputation, moral reasoning, metaphysical speculation, psychical research and mathematical argument, not to mention daily life and all branches of the natural and social sciences.” (O’Donnell 1989, p. 38)

A question that arises from the discussion above is how the degree of rational belief increases or decreases. Here another element of Keynes’s probability appears: the secondary proposition *q*. It is a proposition that describes a particular characteristic of a primary proposition. It is the knowledge of the secondary proposition q, that supports the degree of rational belief in *a/h*. In Keynes’s words,

> “The proposition (say, *q)* that we *know* ... is not the same as the proposition (say, [a])[7] in which we have a probable degree (say, ex) of rational belief. If the evidence upon which we base our belief is *h,* then what we know, namely *q,* is that the proposition [aj bears the probability relation of degree ex to the set of propositions *h;* and this knowledge of ours justifies us in a rational belief of degree ex in the proposition *[a].*” (Keynes, 1973a, p. 11, quoted from O’Donnell 1989, p. 39)

The premise *h* represents all the knowledge (corpus of knowledge) that an individual possesses. So, as the individuals are not identical, the premise *h* will vary between them. The same conclusion could be supported by different sets of premises, as the latter will vary among individuals. It is clear that there is a subjective element in it. However, as noted by O’Donnell (1989, p. 41), this subjectivity of the set of premises *h* does not affect the objectivity of the probability relation, as objectivity refers to the logical relation between *a* and *h,* and not to *h* alone.

Two important things must be clearly understood. First, as mentioned before, the set of premises, *h,* comprehends all knowledge possessed, and it is considered

[7] Keynes uses *a* and *p* interchangeably to represent the set of conclusions. To avoid confusion to the reader we substitute *p* for *a* on Keynes’s quotation.

as direct knowledge and true knowledge (Carvalho 1988, p. 70). The secondary preposition, *q*, is that piece of knowledge that supports the degree of rational belief *a*. that *a* follows from *h*. So, the secondary proposition is also included in *h*. Secondly, the fact that *h* is true knowledge does not imply that complete knowledge is necessary to establish a probability relation. Here the Keynes's concept of uncertainty integrates with the concept of probability. It is impossible to know every piece of information necessary to decide with complete certainty, as Keynes's concept of uncertainty stresses that there are some premises that are unknown and unknowable at the moment of the decision. So, to complete the set of premises, the decision maker has to create additional premises. The probability relation is built upon the set of premises *h*, which are partially true knowledge and partially knowledge created to fill the "voids". In Carvalho (1988, p. 77),

> "Uncertainty and probability, taken in Keynes's sense, are thus complementary concepts, the former relating to the choice of the premises, the latter to the logical development of them."

Thus, the premise is supposed to be known as a truth or assumed by hypothesis to be true. This implies that there are two types of inferences that can be made, according to whether they are supported by known true premises or hypothetical true premises: hypothetical and assertoric inferences. What is important to note is that a premise can never contain propositions whose falsity is known, and they should not be self-contradictory.

A last one important property of Keynes's probability is the assertion that not all probability relations are numerical. On the contrary, in Keynes's view, a probability relation is, in general, a non-numerical quantity:

> "Only probability relations which are of the *same kind* and in the *same unit* of quantity are numerically measurable and therefore numerically comparable.[...] Moreover, this impossibility of numerical measurement is not a product of mental incapacity or lack of knowledge, but it arises from the nature of the case itself." (Carabelli, 1992, p. 8; see also, Carabelli, 1995, p. 138).[8]

Numerical probabilities will be assigned only for those cases where 'the principle of indifference' is appropriate. This principle relies on two kinds of judgement: judgement of relevance (or irrelevance) and judgement of preference (or indifference) (cf. O'Donnell 1989, p. 56). Given two probability relations, *a/h* and *a/hhl'*

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[8] These characteristics of probability explain situations called rational dilemmas. These are analogous to moral dilemmas, such as conflicts of duties and moral rules, which are typical in ethics. In reasoning or in judgement, rational dilemmas arise from the conflict between heterogeneous, opposite or incommensurable reasons that cannot be weighed one against the other using a common scale (Carabelli, 1995, p. 140).

with identical conclusions but a different set of premises, the judgement of relevance implies that:

if $a/h = a/hh_1$ then h_1 is irrelevant to the argument;

if $a/h \neq a/hh_1$ then h_1 is relevant to the argument.

In addition, given two probability relations, *a/h* and *b/h,* with identical premises but a different set of conclusions, the judgement of preference implies that:

if $a/h = b/h$ then there is an indifference;

if $a/h \neq b/h$ then there is a preference

Then, according to O'Donnell (1989, p. 57),

> "The procedure is thus to use judgements of relevance to distinguish between the relevant and irrelevant evidence, and then to determine whether indifference or preference exists between the alternatives on such relevant evidence (T P, 58, 68, 121). If the indifference prevails between the mutually exclusive alternatives, then all are equally probable, and the mathematical calculus may be applied. Consider, for example, a supposedly fair dice with three red numbers and three green numbers. Judgements of relevance determine that the colour differences are immaterial and may be ignored. Judgements of indifference then establish that the probability of throwing any one of the numbers is the same as throwing any other. All six alternatives are thus equiprobable, the probability of each being one-sixth."

Moreover, non-numerical probabilities can be compared only if they conform to either of two standard forms:

> "They have identical premises but the conclusions are different but overlapping *(a/h* and *ab/h)*. In this case $a/h > ab/h$, as the same set of premises has to support a greater set of conclusions 'For example, given black clouds in the sky [h] the probability of rain alone [a] is higher than the probability of rain and hail combined [ah].' (O'Donnell, 1989, p. 58)

> "The inverse case: they have identical conclusions and different but overlapping premises (*a/h* and *ab/h*). In this case, *h* I must have only one independent piece of knowledge. Whether *a/h* is greater or less than *a/hh*,, will depend on whether h_1 is favourable or not. For example, take h = black clouds in the sky and *a* = today will rain. If one has h_t = we are on rain season, as h_1 is favourable premise then $a/hh_1 > a/h$. If h_1 = the weather report says that today there will be no rain, so $a/hh_1 < a/h$."

However, it is important to be note that for Keynes, the cases where ordinal comparisons are possible represent a minority of the situations and even cases where cardinal comparisons are possible, they are not the general case. Usually, the probability relations are incomparable on either ordinal or cardinal terms.

It is clear from the above that probability is a branch of logic, in Keynes's formulation. As pointed out by Carabelli (1988, p. 18), "Keynes's logic of probability appealed to those categories traditionally associated with the theory of belief, opinion, limited knowledge, logical doubt and ignorance, i.e. uncertainty and probability". Logic in this sense is not mainly concerned with demonstrative knowledge or truth relations. It is just the opposite. In Keynes's conception, one important feature is that the arguments, in general, are non-demonstrative and non-conclusive and, thereby completely opposed to Cartesian/Euclidean mode of thought. Moreover, this logic is "non-demonstrative because it referred to organic relations would not be amenable to formal representation" (Dow, 1996, p. 7). Organic relations, in this case, are indivisible and therefore, impossible to be reduced to the smallest part.

Another important concept in Keynes's view of probability is the definition of the weight of argument. It possesses different attributes from probability. The latter could be understood as a balance between favourable and unfavourable evidence. Weight is the comparison between the absolute amounts of relevant knowledge and of relevant ignorance. So, weight and probability are two autonomous and independent properties of an argument. The greater the amount of knowledge (or relevant evidence), the greater the weight of argument. However, nothing could be directly said about the magnitude of the probability. As the evidence increases, this magnitude may either increase or decrease. In O'Donnell's words, "since weight is associated with h and probability with a/h, they are entirely independent properties. As h increases, weight always increases, but probability may rise, fall or stay the same" (1990, p. 256; see also Carvalho, 1995, p. 58).

Weight is an important property of an argument because it indicates some confidence in a specific argument. As it is connected with the total amount of relevant evidence, it can be seen as a " measure" of how well founded an argument is, and thereby, to what extent it is likely to be reliable. "The probability of an argument establishes the degree of rational belief in the conclusion, while the weight of an argument indicates the degree of confidence they are entitled to have about this probability" (O'Donnell, 1990, p. 257).[9]

IV. ANALYSING THE INTRODUCTION OF INNOVATION USING KEYNES'S PROBABILITY

The discussion made in sections II and III above shows that there is an important element linking the NS approach to innovation and Keynes's theory on probability, that is, the decision making under uncertainty. As shown, uncertainty is an irreducible element in innovative activity. It is always present when some techno-

[9] As pointed out by Minsk y, "In truly uncertain situations further information might reduce the degree of confidence without necessarily changing the assessed probabilities, in the case of political crises, for example" (1976, p. *65;* quoted from Lavoie 1992, p. 46).

logical solution is sought. On the other hand, Keynes's theory of probability tries to explain how rational behaviour can emerge from an uncertain environment. Thus, in this section we attempt to interpret the introduction of innovations using the concepts of technological paradigm, technological trajectories and Keynes's theory of probability.

The first aspect to be analyzed is the uncertainty. As shown in section II, for the NS the innovative activity deals with both strong substantive and procedural uncertainties. However, from Keynes's approach to uncertainty (CW, vol. VII), the substantive uncertainty is sufficient to characterize the uncertainty that an innovator faces. The lack of information discussed above is not a problem of imperfect information, but it reflects the fact that the future is unknown and unknowable. The impossibility of knowing *a priori* the length of time that it will take for the innovation to be found; the cost of this innovation; its acceptance by the market, has the same nature as the impossibility of knowing *a priori* "the price of copper and the rate of interest twenty years hence, or the obsolescence of a new invention" as Keynes pointed out (CW, Vol. XIV). From this point of view the uncertainty that appears in Keynes's approach to the investment decision is the same as the uncertainty that appears in the innovative activity in the NS approach. Even in a hypothetical situation where the agent is able to understand all information he/she has received, strong uncertainty will prevail, as it is impossible to know *a priori* how some variables important to the investment will behave in the future.

Moreover, as the investor is dealing with innovation, which by definition is something new, the past cannot be used as a reliable guide. It is not reliable because the world does not behave as an ergodic process (cf. Davidson, 1982-83).[10] Indeed, technological change is one of the most important factors determining the non-ergodicity of the world.[11]

When deciding about whether to introduce an innovation or not, the innovator must have a degree of rational belief in the success of the innovation. It is a decision-making process, where the rationality of the agent can be perfectly interpreted using Keynes's probability.

However, there are important contributions by the NS that help in this decision-making process. First of all, one has to keep in mind that there are different types of innovation with different degrees of uncertainty (Freeman, 1974; Kay, 1979). The most important difference is between radical and incremental innova-

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[10] The non-ergodicity of the world explains the difference between imperfect information and the unknowability of the future. We do not know the future states of the world because some information about the future does not exist in the present. It is not a question of accessibility to information, but rather a problem of non-existence of information.

[11] The relationship between innovation and ergodicity has another important consequence for the use of rational expectations and the new endogenous growth theory. In some of these models (Grossman & Helpman, 1991, for example) steady-state growth is assured by the assumption that the agents behave using rational expectations. However, how can an agent have a rational expectation about something that is completely new? For a detailed discussion about this topic see Setterfield (1994).

tions, where the former is based on completely new knowledge and the latter on pre-existing knowledge.

The decision-making process related to radical or incremental innovation will differ according to the role of the previous knowledge. Here the concepts of technological paradigm and technological trajectory are very helpful contributions by the Neo-Schumpeterians. As discussed in section II, one can, in a simplified manner, identify the introduction of a new TP as a radical innovation, and the development of one of many possible TTs as a process of incremental innovation. So, when one is dealing with a radical innovation the knowledge (premise) that will be used as a ground for the innovation decision is limited and extremely weak, and the response of the market is very uncertain. On the other hand, the incremental innovation is based on existing knowledge, defined by the TP. Moreover, as one develops a TT, by the introduction of successive incremental innovations, knowledge is accumulated and so, the premise for the decision becomes better founded. As the premises become greater and the new premises are favourable, using Keynes's concept of probability one can say that the degree of rational belief in the success of the innovation becomes greater too. Let us develop the argument further.

One of most important kinds of knowledge is tacit knowledge – that knowledge that comes from experience and is not codified in manuals or books. This tacitness is a fundamental factor in the cumulative aspect of the innovative activity. As one walks through a TI, one's knowledge increases for two reasons: (i) the innovator improves his/her understanding of the technology that he/she is using[12]; (ii) also, he/she improves knowledge about market behaviour in relation to this previous innovation. Thus, there is a learning process, that is very similar – maybe identical – to the learning process which is implicit in Keynes's theory of probability. As the weight of argument was defined above as the relation between relevant knowledge and ignorance, the progress along through a TT increases the weight of argument and, as a consequence, the state of confidence in the success of the introduction of a new innovation becomes greater.

Moreover, at each improvement of a product/equipment the investor becomes better informed both about the market behaviour in relation to the innovation and about the technology itself. So, the set of premises is increasing, and as the past innovations have been successfully introduced, the new premises work to increase the DRB on the introduction on a new innovation.

Now it becomes clear how the concept of routines and Keynes's probability provide a very interesting tool in the understanding of the process of technical change. As shown before, routines are the rational behaviour used by the innovator to deal with the procedural uncertainty. They comprehend the knowledge accumulated, and they are constrained by the TP. However, as the strong substantive un-

[12] *Remember that technology is never a free good. The technological solution for one specific problem is always constrained by the technical characteristics of the technological paradigm, and these characteristics are not known ex-ante.*

certainty is never completely eliminated, another element has to be introduced in the decision process, that is Keynes's probability and the concepts of DRB and weight of argument. The learning process that occurs during the continuous innovative activity weakens the influence of some sources of the uncertainty related to the investment process. The basis on which successive decisions to introduce innovation is founded becomes more grounded as both weight of argument (state of confidence) and the DRB increase, driving the formation of the expectation in the same direction.

Thus, one can say that routines form the premises (h) upon which the decision is taken. Based on these routines, a DRB (a) on the success of the introduction of the innovation can be established, and as new routines are developed as a result of the innovative process, the weight of argument changes.

It is important to note that the characteristics of TP and TT, such as cumulativeness, tacitness of knowledge, appropriability, introduce an element of endogeneity of the formation of expectation. In Dosi's words (1988, p.1134),

> "[...] technological trajectories are not only the ex-post description of the pattern of technical change, but also, as mentioned, the basis of heuristics asking 'where do we go from here?'."

What Keynes's probability does is to help to understand how this partial endogeneity emerges from those technological features.

A model of introduction of innovation using Keynes's probability and NeoSchumpeterian approaches

The question faced by the innovator when deciding whether or not to introduce an innovation is about the profitability of the innovation. In Keynes's probability terms the question is: What is the degree of rational belief (a) on the success of the introduction of an innovation (conclusion a) given the features of the TP and TT (premises *h*)? Formally we have:

ag_{tj} = conclusion (propositions): "the innovation gi will be profitable", where:

t = time of the introduction of the innovation;

j = technological age of the innovation;

if g_{tj} is a radical innovation, so $j = 1$;

if g_{tj} is an incremental innovation, so $j > l$;

if g_{tj} is a replacement, so $g_{tj} = g_{(t-1)\,(j)}$;

h_1 = set of premises (propositions) at time t;

basically it is the knowledge about the variables that affect the investment decision, including the knowledge about the technical characteristics of the new innovation, or in other words, the knowledge about the TP and TT;

q_t = is the secondary proposition at time t: the knowledge of the outcome (successful or not) of the introduction of the innovation $g_{(t-1)\,(j-1)}$;

If g_{tj} is a radical innovation, there is no secondary proposition So, *animal* *spirits* will be the most important factor in deciding whether or not an innovation should be introduced;

$V_t(ag_{tj}/h_t)$ = is the weight of argument at time t, with the premises h ; which means the relevant knowledge about the technological trajectory in relation to its potential frontier.

Thus, what one wants to know is a, in relation to ag/ h,or DRB (ag/ In other words, the Degree of Rational Belief in a at time t for the innovation g, which has a technological age of j.

Now, one has to try to analyze the question put above in such a way as to incorporate the concepts of technological paradigm and technological trajectory. When one starts to develop a TT, it is a radical innovation which is being introduced. So, the innovator has to attempt to define the degree of rational belief in the profitability of this innovation in such a way as to decide whether he/she will invest or not. He/she makes the decision grounded on the premise h, the secondary proposition q, and the probability relation a!h. Schematically, at time t = 1, one has:

DRB $(ag_{11}) = \alpha_1$ or $ag_{11}/h_1 = \alpha_1$;

the weight of argument, $V_1\ (ag_{11}/h_1)$;

and the secondary proposition *q*,, which in this case will be very weak.

So, it is the *animal spirits* that will support a,.

At time *t* = 2, one has:

DRB $(ag_{22}) = \alpha_2$ or $ag_{22}/h_1h_2 = \alpha_2$;

the weight of argument, $V_2(\ ag_2/h_1h_2)$;

and the secondary proposition q_2,

where: $ag_{22}/h_1h_2 > ag_{11}lh_1$ (or $\alpha_2 > \alpha_1$), as one now has a q_2 greater than q_1;

$V_2\ (ag_{22}/h_1h_2) > V_1(ag_{11}/h_1)$, as the amount of relevant information that one has is greater at time 2 than at time 1.

What it is important here is to understand the occurrence of three processes: after introducing the innovation g,1 at time 1, the investor goes through a process of learning, which creates a tacit knowledge about the innovation. This allows him/her to increase his/her understanding about the possible future improvements in the innovation. Thus, there is an increase of the direct knowledge (q);

as this knowledge is tacit, the asymmetries between the investor and his/her competitors increase, increasing thus confidence that he/she will be not superseded by another competitor with a better innovation;

as the innovation g_{11} was introduced with success – it has been accepted by the market – the investor becomes more confident about the possibility of success of the incremental innovation g_{22}

These processes operate to increase the weight of argument for the investment decision at time *t* = 2 $(V_2\ (ag_{22}/h_1h_2))$ As one can see, despite the fact that they are independent, both the probability relation and the weight of argument increase in the process of incremental innovation.

If now one considers the continuous introduction of incremental innovations, as one goes through the TT, one can schematize this process as follows:

Time	Technological Age	Degree of Rational Belief	Weight of Argument	Secondary Proposition
t = 1	j = 1	DRB $(ag_{11}) = \alpha_1$	$V_1(ag_{11}/h_1)$	q_1
t = 2	j = 2	DRB $(ag_{22}) = \alpha_2$	$V_2(ag_{22}/h_1h_2)$	q_2
t = 3	j = 3	DRB $(ag_{33}) = \alpha_3$	$V_3(ag_{33}/h_1h_2h_3)$	q_3
:	:	:	:	:
t = n	j = n	DRB $(ag_{nn}) = \alpha_n$	$V_n(ag_{nn}/h_1h_2h_3 \ldots h_n)$	q_n

Where: $\alpha_{t+1} > \alpha_t$
$V_{t+1}(ag_{(t+1),(j+1)}/h_1 \ldots h_{t+1}) > V_t(ag_{tj}/h_1 \ldots h_t)$, and
$q_{t+1} > q_{t.}$

V. CONCLUSION

We think that the ideas outlined above could represent a possible link between the Neo-Schumpeterian approach to technical change and Keynes's theory of probability. First, the NS approach to innovation stresses the importance of uncertainty as a feature that is always present in the innovative activity and can never be eliminated. To deal with this uncertainty NS theorists developed the concept of routines. Moreover, the concept of technology used by this approach sheds light on features such as cumulativeness, appropriability and knowledge base, which are incorporated in the concepts of technological paradigm and technological trajectory. These factors delimit the shape the routines use to deal with the uncertainty.

However, as the uncertainty is never eliminated, routines by themselves are not sufficient to explain the decision-making process during the introduction of an innovation. They explain the selection of the premises used in this process, but they do not explain the logical development of this choice. A decision remains to be made: whether to introduce an innovation or not. Should one continue to research for better developments or are the present outcomes from R&D activities sufficient to guarantee the success of the innovation? Routines are not sufficient to answer this question.

At this point, we think, and have tried to show, that Keynes's theory of probability can help understand this last decision. The use of Keynes's probability makes possible to identify the rationality involved in this process, even in situations of strong uncertainty. Despite the fact that one can never know for certain if the innovation will be a success, in most of the time there will be a Degree of Rational Belief on the success of the introduction of this innovation. This DRB, together with the Weight of Argument, can offer a partial reliable guide to conduct, based on which the rationality that is behind the development[13] of a technological trajectory could be explained.

What is important here is to note that in cases of strong uncertainty, the rationality of the agent cannot be explained by theories, which are appropriated to risk situations, as for example, the Subject Utility Theory. This does not mean that an innovator always acts based only on the "animal spirits". When one has to find a solution for a technological problem, one follows his/her routines, and after that he/she decides to introduce or not an innovation based on the *Degree of Rational Belief* and on the *Weight of Argument* that he/she has on the success of the introduction of an innovation. So, there is a rationality behind one's acts, despite the fact that he/she does not have a perfect knowledge of the future or without known the probability distribution of future outcome, even the possible outcome itself.

If we are able to agree with the interpretation of the technological change process as shown above, the next step is to discuss the consequences of this approach for the investment decision process, since the introduction of an innovation can be seen as an investment decision.[14] However, as the discussion of this question is beyond the aim of this paper, we will only suggest a possible line to be explored on another occasion.

The most important consequence concerns the possibility that the concepts of technological paradigm and technological trajectory can be used to shed light in the elements of continuity in the introduction of innovation. In other words, the cumulative aspect of technical change can, with all the precautions that this discussion deserves, introduce an element of endogeneity in the formation of investment expectations.[15] As shown above, the technical and market successes in the introduction of a previous innovation are, when considered within the framework of technological paradigm and technological trajectory, powerful elements in the formation of the expectation for the next development of this innovation, since they work directly on the formation of the *Weight of Argument* and on the *Degree of Rational Belief*. Thus, in terms of the individual investor, there is a chain between the outcome of the introduction of an innovation and the premises selected for the decision about the introduction of the next innovation.

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[13] The introduction of a complete new technological trajectory is a quite different case, as the premises that one has is weak and, so, the weight of argument is low. Thus, as we said before in this case "animal spirits" prevails.

[14] Despite the differentiation among types of innovation (from radical to incremental), all kinds can be treated as investment as all have, to varying degrees the essential characteristics of the investment in physical asset: uncertainty and illiquidity. This is true even when the innovation is only a product differentiation. Before its introduction, money is spent on research and development of the innovation and on the setting up of the line of production; these kinds of decisions cannot be reversed without cost. Moreover, it is clear that what one aims for when introducing an innovation is the valorization of its capital. One looks for profits. So, from this point of view, the introduction of an innovation can be viewed as a portfolio choice, as in Keynes's approach.

[15] For a discussion on the conditions for endogeneity in the formation of investment expectations see Possas (1989).

The big question is about the investment as role, which means the step from the micro-level to macro-level. Would this process, that looks good at the microlevel, be replicated at the macro-level? The answer to this question could be found in the study of the diffusion process, with the help of the concept of meta-paradigm (Freeman & Perez, 1988). There is a further important question that remains to be answered: What happens when money is introduced into this framework? Whatever the outcome of these discussions, it is clear that the linking of the NS approach to innovation with Keynes's theory on probability will make a substantial contribution to the understanding of the investment process.

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