The future's unknowability: Keynes's probability, probable knowledge and the decision to innovate

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Abstract: The aim of this paper is to show that Keynes's concept of probability can enrich the understanding of the process of introduction of innovation offered by the Neo-Schumpeterian approach. Keynes's theory of probability can complete the set of tools required to understand the decision process of whether or not to introduce an innovation mainly by complementing the notion of routines.

Key-words: uncertainty; probability; Keynes; technical change; innovation.

Sobre a imprevisibilidade do futuro: a teoria da probabilidade de Keynes, o conhecimento provável e a decisão de inovar

Resumo: *O objetivo deste artigo é mostrar que o conceito keynesiano de probabilidade pode contribuir para o entendimento do processo de introdução de inovações tal qual explicado pela abordagem neo-Schumpeteriana. A teoria da probabilidade de Keynes tem o potencial de completar a caixa de ferramentas necessária para analisar a decisão sobre introduzir ou não uma inovação, principalmente ao complementar a idéia de rotinas.*

Palavras-chave: *incerteza; probabilidade; Keynes; mudança tecnológica; inovação.*

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Introduction

The aim of this paper is to show that Keynes's concept of probability can enrich the understanding of the process of introduction of innovation offered by 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 Probable Knowledge and Weight of Argument, drain from Keynes's theory of probability, when used together with the concept of routines, can clarify the rationality of the decision-making process in the introduction of an innovation. In section 1, the main features of Keynes's probability and the concept of probable knowledge are presented. In section 2, I describe those aspects of the Neo-Schumpeterian approach to technology that are important for our discussion. The possible links between these approaches are discussed in section 3. Finally, section 4 concludes with suggestions for further development.

1. Keynesian Uncertainty

The concept of uncertainty in Keynes has been a subject of debate since the publication of the *General Theory*. Initially, the main feature of this discussion was the distinction between "risk" and "uncertainty"[2]. While the Neoclassical approach argued that only situations of risk were analytically tractable in economic analysis, e.g. Lucas, heterodox schools – especially the Post-Keynesians – maintained that economic analysis should not neglect 'true' uncertainty. However, since the early years of the 1980's the debate has changed. Despite the fact that the previous distinction still remains, within the heterodox field a discussion about the existence or not of Keynes's concept of uncertainty in the *Treatise on Probability* and its link to the *General Theory* has emerged (Carabelli 1985, 1988, 1992, 1995; O'Donnell 1989, 1990; Lawson 1985, 1988; Runde 1990, 1991, among others). Thus, we think that it is important to look at the *Treatise on Probability* before we define what is understood here as Keynesian uncertainty[3].

2 This distinction first arises in Knight's works (1921:20): "It will appear that a *measurable* uncertainty, or 'risk' proper, as we shall use the term, is so far different from an *unmeasurable* one that it is not in effect an uncertainty at all. We shall accordingly restrict the term 'uncertainty' to the cases of the non-quantitative type".

3 We will not discuss Keynes's theory of probability in its details as this discussion has already been done by other scholars. For the present we will only make a brief presentation of the general ideas.

For Keynes, probability is about logical relations between sets of propositions, premisses and conclusions. Let the conclusions be the set of propositions *a*, and the set of premisses, *h*. If a knowledge of *h* justifies a rational belief in *a* of some degree, one can say that there is a probability relation between *a* and *h*. This relation can be written as: a/h.

The probability relation or the degree *a* of rational belief that it entails ranges from a situation of certainty ($a/h = 1$), meaning that the relationship between *a* and *h* is tautologic, to a situation of impossibility ($a/h = 0$), where *a* and *h* are contradictory. A situation where $0 < a/h < 1$, means that the probability relation warrants, a degree of belief intermediate between 0 and 1. Moreover, the probability relation is defined solely in terms of the relation between the conclusion and the premisses. If, after establishing a probability relation of type a/h, new evidence h_1 appears, this does not invalidate the previous probability relation, but gives rise to a new one: a/hh_1. An important feature of Keynes's theory of probability is that not all probability relations can be numerically measurable.

What is important is that in Keynes's approach probability is a branch of logic. As pointed out by Carabelli (1988:18), "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 restricted to demonstrative knowledge or truth relations. According to Keynes, probability arguments, in general, are non-demonstrative and non-conclusive and thereby generally opposed to Cartesian/Euclidean mode of thought. Moreover, this logic is "non-demonstrative because it referred to organic relations that would not be amenable to formal representation" (Dow 1996:7)[4].

An interesting way to represent Keynes's theory of probability is suggested by Koopman (1940). In this article, he defines the axioms and the algebra of *intuitive probability,* and he identifies Keynes's theory of probability as a case of *intuitive probability*. The *intuitive* thesis in probability grasps that probability derives directly from the intuition, both in its meaning and in the majority of laws which it obeys. Contrary to the common use of probability, the *intuitive* approach claims that experience should be interpreted in terms of probability and not the inverse. Thus, *intuition* comes prior to objective experience. The main aphorism of this thesis is that "*knowledge is possible, while certainty is not*" (Koopman 1940:269, italics added).

4 According to Dow (1996:15): "An organic system involves interdependencies which preclude the selection of one set of axioms as universally causal; it also involves interdependencies which are complex and evolutionary, and thus not amenable to formalization with respect to separable elements within a single system of reasoning."

The importance of the intuitive probability to our discussion is that it simplifies the conditions for the comparability between probabilities, without discrediting the main aspects of Keynes's interpretation. According to Koopman (1940, p. 270), "the fundamental view point of the [intuitive probability] is the primal intuition of probability expresses itself in a (partial) ordering of eventualities."

Let a_1, h_1, a_2, and h_2 be propositions, where the meaning is perceived by an individual that does not know whether this apprehension is true or false.

> Then the phrase "[a_1] on the presumption that [h_1] is true is equally or less probable than [a_2] on the presumption that [h_2] is true" conveys a precise meaning to his intuition. (...) That is, (...) a first essential in the thesis of intuitive probability, and contains the ultimate answer to the question of the meaning of the notion of probability (Koopman 1940:270).

This could be represented in symbolic forms of comparison in probability as:

$$a_1/h_1 \geq * \, a_2/h_2$$ [5]

This is precisely the kind of comparison that Keynes discusses in the *Treatise on Probability*. So, hereafter we will use the above symbolic form to describe Keynes's approach.

Another important element on the Keynes approach is the concept of weight of argument. Keynes's main concern in discussing probability is to show that one can act rationally in situations where complete certainty about the future is absent. In these situations one should look not only at the probability relation but also at the size of the evidence – evidential spread – that supports this probability. Here Keynes brings in to discussion the concept of weight of argument.

According to Runde (1991), it is possible to find in the *Treatise* a relative definition of weight, as it is referred to the *degree of completeness of the information set on which a probability is based*. It is the balance between the amount of relevant knowledge in relation to the relevant knowledge plus relevant ignorance possessed. This is expressed, according to Runde (1991:281), as

$$V(a/h) = K_r/(K_r + I_r)$$

5 Where "≥ * is the qualitative probability relation 'at least as probable as' " (Runde 1997:223).

where: K_r is the relevant knowledge and

I_r is the relevant ignorance.

Two aspects deserve more attention. The first one is related to the meaning of "relevant ignorance". As insightfully pointed out by Runde (1991), it is always possible to know, or at least identify, the factors that affect our probability relation, and about which one is ignorant. Secondly, more information does not necessary mean an increase on the weight of argument. New evidence could decrease the weight if it implies the increase of relevant ignorance. A new piece of evidence can show that our previous relevant knowledge was wrong – decreasing the weight – albeit, simultaneously, the apprehension of the relevant ignorance is increasing.

Finally, it is well known that Keynes assumes a direct relationship between weight and *confidence* in using the probability estimate as a guide to conduct. The definition of weight as a *degree of completeness of information* is helpful to the understanding of this relationship. Confidence can either decrease or increase with new information, because new evidence can increase the relevant ignorance or knowledge.

It is important to note that the Keynes approach to probability and the concept of weight allow a definition of a different kind of knowledge, that is *probable knowledge*. It is that kind of knowledge that is obtained from the possibility of establishing a probability relation and from the information set that grounds it. It is a knowledge that emerges in situations of true uncertainty and it is different from the probabilistic knowledge. The latter is that knowledge that comes out in situations where the use of probability distributions is possible, in other words, situations of risk.

These two main aspects of the *Treatise* – probability relation and weight of argument – have been used by some scholars (Runde 1990; Dow 1996) to define uncertainty in a Keynesian sense and, in addition, to demonstrate that Keynesian uncertainty admits degrees. Runde (1991, 1990) argues that uncertainty, according to Keynes's approach, could be related to the size, in some sense, of the information set upon which the probability relation is based. In other words, uncertainty can be related to the weight of argument if the latter is defined as a *degree of completeness of information on which a probability is based*. Despite the fact that this notion is not fully explored in the *Treatise*, Runde gives two quotations from *The General Theory* that support his claim that uncertainty can be related to the weight of argument:

> The state of long-term expectations, upon which our decisions are based, does not solely depend, therefore, on the most probable forecast we can make. It also depends on the *confidence* with which we make this forecast – on how highly we rate the likelihood of our forecast turning out quite wrong (C.W. VII:148).

And:

> The liquidity-premium, it will be observed, is partly similar to the risk-premium, but partly different; - the difference corresponding to the difference between the best estimates we can make of probabilities and the confidence with which we make them (C.W. VII:240).

It is clear from the previous quotations that *confidence* is the essential factor in this interpretation of uncertainty. As it was shown above, the concept of weight, as a *degree of completeness of information,* appears to be the best one to capture the role of *ignorance* on the assessment of the *confidence* on the probability relation. As a consequence of this approach, the *complete* absence of probable knowledge should be interpreted as the extreme case of uncertainty. If it is impossible to establish the probability relation, whatever the reason – no existence of probability or lack of skill to determine or identify it –, it is also impossible the existence of any *confidence*. Thus, this situation could be interpreted as an extreme case not only for uncertainty, but also for *confidence*.

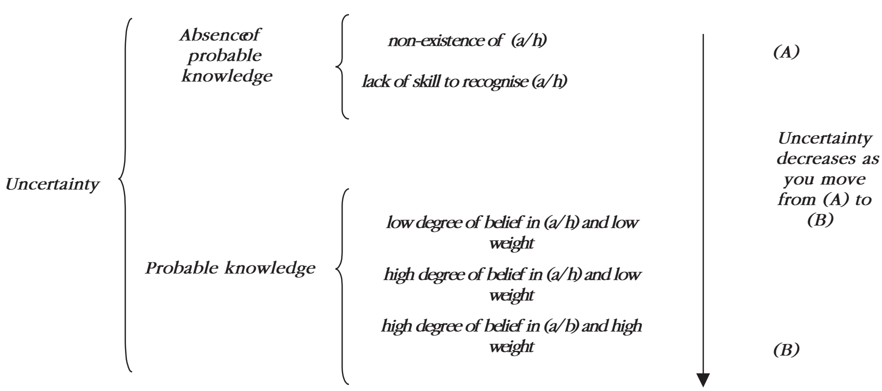
From this extreme position, one can move to situations where uncertainty prevails due to low weight of argument, which implies low *confidence*. Thus, there is a *qualitative* change in the uncertainty, from a situation of which a probability relation does not exist to another one in which probability relation exists but the weight is low. Moreover, as the weight of argument is increasing, the confidence follows in the same direction and the uncertainty decreases. In this approach, probable knowledge is taken into account as a guide to conduct, and the degree of reliability of this probable knowledge – the *confidence* it merits – determines the *degree of uncertainty* that exists in a specific situation. Therefore, the concept of weight allows the understanding of uncertainty as a relative concept.

Dow (1995) goes further in the development of the concept of degrees of uncertainty. She argues that to take weight into account in defining uncertainty, one must bring to consideration the knowledge of what constitutes relevance. To do this, it is necessary to have a "degree of belief in a hypothesised structure on which to base an estimate weight" (Dow 1995: 124). In other words, a degree of belief that there is a logical relation between the hypothesis (a) and the evidence that bears it (h). This is important for to identify relevance it is necessary to believe that the relationship between (*a*) and (*h*) is known. The main point here is to note that there is a difference between the acknowledgement that it is possible to establish a logical relation between *a* and *h*, and to define in what extent the size and quality of *h* allows the conclusion *a*. One has now two orders of uncertainty that work together. First, there is uncertainty about the probability relation. As she precisely pointed out, it is a case of 'uncertainty about uncertainty'. Uncertainty now is inversely related to a lower order of knowledge of the probability relation relative to ignorance of relevant evidence and ignorance. Second, there is uncertainty about the *degree of completeness of information on which a probability is based*. From this perspective, the limit situation is that one where knowledge about the probability relation is absent and ignorance is complete[6].

Summing up this section, we think that we could define Keynesian uncertainty as that situations in which decision-makers do not have access to numerically definite probabilities, whatever it is[7]. Under this definition of uncertainty, it is possible to explain qualitatively different situations. Both, the extreme situation of uncertainty – complete absence of probable knowledge, whatever the reason –, and the situation of probable knowledge, where weight is interpreted as a measure of gradability of uncertainty fit the definition above, eluding any confusion.

Qualitative degrees of uncertainty can be visualised in table 1.

TABLE 1 - SCALE OF QUALITATIVE DEGREES UNCERTAINTY



6 However, this situation is admitted as not feasible: "As uncertainty is compounded at higher recursive levels, our necessary conceptual structures become complex, counterintuitive and involuted to the point that they collapse under their own weight. Put in another way, absolute ignorance is incompatible with knowledge of absolute uncertainty" (Dow 1995: 124).

7 As pointed out by Runde (1998:3), this definition follows the lines of Knight's definition.

2. Technical change and uncertainty

Until the second half of the 1970's most 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[8]. However, by the end of the 1970's 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 could alone provide the elements for the full comprehension of the technological change process. This group will be named here Neo-Schumpeterian (hereafter NS), as they find in Schumpeter's writings the inspiration for their analyses[9].

An important feature of the innovative activity according to the NS is the uncertainty. It plays an essential role in the understanding of technical change by the NS approach. According to Freeman and Soete (1997:242-5), 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 kind of uncertainty is not specific to the innovative activity, but to economic decisions as a whole. The other two kinds of uncertainty are project-specific. Technical uncertainty refers to realised 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 1979:18).

Despite the fact that these categories of uncertainty appear in every innovation, their degree varies according to the type of innovation. Freeman and Soete (1997:244) show 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 (Table 2). This difference in the degree of uncertainty is related to the development of

8 For a review about the critics to these approaches see Dosi 1982.

9 This group is also called evolutionary or institutionalist. However, as theses 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.

technological paradigm and technological trajectories (hereafter TP and TT respectively), 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: 1134)[10].

TABLE 2 - DEGREE OF UNCERTAINTY ASSOCIATED WITH VARIOUS TYPES OF INNOVATION

1	True uncertainty	Fundamental research Fundamental invention
2	Very high degree of uncertainty	Radical product innovations Radical process innovations outside firm
3	High degree of uncertainty	Major product innovations Radical process innovations in own establishment or system
4	Moderate uncertainty	New 'generations' established products
5	Little uncertainty	Licensed innovation Imitation of product innovations Modifications of products and processes Early adoption of established process
6	Very little uncertainty	New 'model' Product differentiation Agency for established innovation Late adoption of established process innovation and franchised operations in own establishment Minor technical improvements

Source: Freeman and Soete, 1997:244.

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

> *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 recognise 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 search for a solution for a technological problem, he/she lacks some fundamental information, and this lack of information makes the

10 It is important to note that although uncertainty can be *reduced*, it is never *eliminated*. According to Dosi (1988:1134), "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).

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 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 information, and the latter depends on the computational and cognitive capabilities of the agents. Therefore, uncertainty here has its source on the lack of knowledge, despite the fact that information could be available. To deal with this uncertainty the agents develop a "rational behaviour", which implies the search for stable rules and procedures (routines), which give the agent some security to face uncertainty.

The use of routines in innovative activity may sound a little odd as innovation represents something new. However, there is no contradiction in this approach. What should be clear is the difference between the "search" for an innovation and the outcomes of this "search"[11]. The uncertainty relates to the outcomes of the research activity and not to this activity itself. One could correctly argue that at initial stages of the research activity the uncertainty is strong. Nevertheless, as some knowledge becomes consolidated or, in other words, as some *heuristics* has been established, one could assume strong patterns (routines) of a high predictability in the research activity. The words of Nelson and Winter (1982:133) synthesise the point:

> We propose to assimilate to our concept of routine all of the patterning of organizational activity that the observance of heuristics produces, including the patterning of particular ways of attempting to innovate. (...) But we emphasize, (...), that viewing innovative activity as "routine" in this sense does not entail treating its results as predictable[12].

11 In Nelson and Winter words: "(...) the relationship of routine behaviour to innovation is centered on a simple distinction between organizational *activity* directed to innovation (or problem-solving more generally) and the *results* of such activity" (1982:132).

12 Nelson and Winter give an illustrative example: (...) the case of systematic sequential search of a well-defined population for an element with attributes that makes it the solution to a well-defined problem. When and whether a solution will be found may be quite uncertain, but the search itself follows a routine with a simple structure: select element, test for desired attributes, terminate with success if attributes are present, select next element if they are not (1982:132).

By placing the discussion in the terms discussed before, one can say that the research routines codify the procedures and knowledge involved in the solution of a particular problem, and are conditioned by the technological paradigm[13].

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 them, 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, 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.

The question to be raised here is whether routines are sufficient to understand the decision to introduce and/or develop an innovation. My claim is that it is not. Routinesed behaviour is not only a characteristic of the innovative activity, but rather it is present in every situation of human life. Indeed, some authors (Farmer 1995; Giddens 1984; Lawson 1997) argue that it is an important element of human action. It is related not only to situations of uncertainty but it is essential to both facilitate the interactions between individuals and give "ontological security" (sense of stability and sameness) to human beings.

Thus, as a part of today situations, routines cannot by themselves alone explain the behaviour of the innovator faced with uncertainty. They are part of this behaviour and must be taken into consideration, nonetheless they are insufficient to provide a full understanding of it. As pointed out by Fransman,

> [w]hile the routine-based approach does not assume certainty, it does not deal adequately with the way in which uncertainty is confronted in decision making in the firm (1998:175).

In technical change's case, 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

13 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).

> 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 1991:150).

However, the last act of a problem-solving activity (choice) under uncertainty remains to be made. That is to say, which course of action should be taken by the agent? What is it that makes an investor decide between the immediate introduction of an innovation or postponing it? 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.

3. Analysing the introduction of innovation using Keynes' probability

The discussion made in sections 1 and 2 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 technological solution is sought. Moreover, Keynes's theory of probability tries to explain how rational behaviour can emerge within an uncertain environment. Thus, in this section we attempt to interpret the introduction of innovations using the concepts of technological paradigm, technological trajectories and probable knowledge.

The first aspect to be analysed is the uncertainty. To make the argument clearer, we first analyse the effects of technological and market uncertainty on the innovative decision, assuming that the business uncertainty is very low at this point. By the end of the chapter, business uncertainty is incorporated into the argument.

As shown in section 2, for the NS innovative activity involves two sources of uncertainty: the incompleteness of the information set and knowledge incompleteness. However, it is worth noting that these two sources of uncertainty fit well with the definition of Keynesian uncertainty discussed before. The *incompleteness of the information set* is nothing more than a problem of low *weight*. What is missing in the information set is the relevant knowledge about the innovation. Moreover, the acknowledgement of the existence of relevant ignorance creates uncertainty. 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, all have the same nature, as e.g. 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 (*C.W.* Vol. XIV). Moreover, *knowledge incompleteness* can also be interpreted either as a situation of *lack of skill* in recognising the main probability relation (*a/h*). The specification of the sources of uncertainty by the NS approach only helps to understand the different degrees of uncertainty associated with different innovations. However, from a theoretical point of view, the Keynesian approach, being more comprehensive, is capable of encompassing the NS approach to uncertainty. Thus, as a starting point to the discussion here proposed, we think that the use of Keynesian uncertainty can provide new insights to the analysis of technical change.

The second aspect to be analysed is the knowledge used in an innovative activity. There are important contributions from the NS that help understanding this aspect. First of all, one has to keep in mind that there are different types of innovation with different degrees of uncertainty (Freeman & Soete 1997; Kay 1979). Roughly speaking, the most important difference is between radical and incremental innovations, 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 NS. 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. Therefore, in the case of radical innovation, the knowledge (premisse) that will be used as a ground for the innovation decision is limited and extremely weak, and the future response of the market is very uncertain. In other words, there is a low reliability on the evidence that is used to decide whether to introduce an innovation. On the other hand, the incremental innovation is based on existing knowledge, defined by the TP. Moreover, as one develops along a TT, the introduction of successive incremental innovations result in the accumulation of knowledge and so the premise for the decision becomes better founded.

One of the most important kinds of knowledge is tacit knowledge – that knowledge that comes from experience but is not codified in manuals or books. Tacitness is a fundamental factor in the cumulative aspect of the innovative activity. As one moves along a TT, one's knowledge increases for two reasons: (i) the innovator improves his/her understanding of the technology that he/she is using[14]; (ii) also, he/she improves knowledge about market behaviour in relation to this previous innovation. Thus, there is a learning process, which is similar to the learning process that is implicit in Keynes's theory of probability. What is changing in this process is the weight, defined as the degree of completeness of the information set. A successful move through the TT increases the relevant knowledge about the technology and the market behaviour in relation to this specific technology and, simultaneously, decreases the relevant ignorance. 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 set of premises is increasing, and as the past innovations have been successfully introduced, the new premises work to increase the probable knowledge about the success of the introduction of a new innovation. This approach helps understanding the different degrees of uncertainty associated with different kinds of innovation.

As said before, probable knowledge can be seen as a guide in situations where uncertainty prevails, and the degree of reliability in this probable knowledge – confidence – determines the degree of uncertainty that exists in a specific situation. In the case of the development of a technological trajectory, one can see that the probable knowledge about the success of the introduction of an innovation is increasing and so the reliability on this probable knowledge as a guide to conduct increases as well. Thus, confidence is increasing and the degree of uncertainty decreasing.

However, there are situations in which the introduction of an innovation is not successful or the search for technological solutions leads to a creation of a new knowledge that increases the uncertainty about the future[15]. In these cases, the relevant ignorance is increasing due to ignorance about market conditions (meaning the acceptance of the innovation) or due to ignorance about the technology itself. In both cases, the weight is decreasing and so the confidence. Thus, the degree of uncertainty increases and may either determine a change on the technological trajectory or show the need for more research in the same trajectory. In any case, these situations imply a decrease in the confidence in the introduction of the next innovation.

14 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*.

15 This is very common in situations where new knowledge contradicts previous knowledge taken for granted.

What has so far been discussed can be formalised in the following way. The main question faced by the innovator when deciding whether or not to develop and introduce an innovation is about the profitability of the innovation. In Keynes's probability terms, the question is: What is the reliability 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_j = conclusion: "the innovation g_j will be profitable", where:

j = technological age of the innovation;

if g_j is a radical innovation, then $j = 1$;

if g_j is an incremental innovation, then $j > 1$;

h_j = set of premises when the innovator is deciding whether or not to develop and introduce an innovation j;
basically h_j is the knowledge about the variables that affect the investment decision, including the knowledge about the technical characteristics of the new innovation, the knowledge of the outcome (successful or not) of the introduction of the innovation g_{j-1}, or, in other words, the knowledge about the TP and TT.

$V_j(ag_j/h_j)$ = is the weight of argument related to the development and introduction of an innovation j; V_j means the relevant knowledge and relevant ignorance about the technological trajectory in relation to its potential frontier.

Thus, what one wants to know is whether the existent probable knowledge is a reliable guide, in other words, the probable knowledge about "*a*" (success) for the innovation *g*, which has a technological age of *j*.

Now, one has to try to analyse the question put above in such a way as to incorporate the concepts of technological paradigm and technological trajectory. Table 3 below can help understanding this process. It incorporates tables 1 and 2 and introduces some elements of Keynes's theory of probability. Following Dow's approach, let us call the probability relation *ag/h* the structure. At the beginning of the development of the trajectory, probable knowledge does not exist due to either the absence of the probability relation or the lack of skill to recognise it. This is the extreme case of uncertainty and *animal spirits* or institutional factors will determine the decision of whether developing the trajectory.

A qualitative change occurs when one moves from stage 1 to stage 2. A previous fundamental discovery has been made and thus, it is possible now to recognise the probability relation, despite the fact that some degree of uncertainty about it exists (this explains the low order of knowledge of the structure ag_j/h_j). In this case, the weight of argument is very low due to the acknowledgement of the relevant ignorance that exists in this phase. Both the technological knowledge and the market responses to the innovation are very weak and so the degree of uncertainty is very high.

When the major innovations start, the knowledge about the structure has already been established, but the relevant ignorance is still greater than the relevant knowledge and so a high degree of uncertainty prevails.

What it is important here is to understand the occurrence of three processes:

a) after introducing the innovation g_2, the investor goes through a process of learning, which creates tacit knowledge about the innovation. This allows him/her to increase his/her understanding about the possible future improvements in the innovation;

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

c) as the innovation g_2 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_3.

These processes operate to increase the weight for the next innovation, decreasing the degree of uncertainty attached to each innovation. At the end of the trajectory (product differentiation) the relevant knowledge – technological and economic viability – is very well established and there is a very low degree of uncertainty. A good example of this situation is the computer industry nowadays. For the firms that are well established in the market, the uncertainty inherent to the decision about the introduction of a new generation of personal computer is very little due to the relevant knowledge these firms possess.

TABLE 3 - TYPES OF INNOVATION AND DEGREES OF UNCERTAINTY

Type of innovation (Technological trajectory)	Order of knowledge about the structure	Weight of argument $V_j = K_j / (K_j + I_j)$	Probable knowledge ag_j/h_j	Degree of uncertainty (υ_j)
Fundamental research Fundamental invention j = 1	Non-existent	Non-existent	absent or lack of skill to recognise ag_1/h_1	υ_1 : True uncertainty (extreme case)
Radical product innovations Radical process innovations outside firm j = 2	Low order of knowledge of structure	V_2 : Very low weight $K_2 < I_2$	ag_2/h_2	υ_2 : Very high degree of uncertainty $\upsilon_2 < \upsilon_1$
Major product innovations Major process innovations in own establishment or system j = 3	High order of knowledge of structure	V_3 : Low weight $V_3 > V_2$ $K_2 < K_3 < I_3$	$ag_3/h_3 > ag_2/h_2$	υ_3 : High degree of uncertainty $\upsilon_3 < \upsilon_2$
New 'generations' established products j = 4	High order of knowledge of structure	V_4 : Medium weight $V_4 > V_3$ $K_3 < K_4 \approx I_4$	$ag_4/h_4 > ag_3/h_3$	υ_4 : Moderate uncertainty $\upsilon_4 < \upsilon_3$
Licensed innovation Imitation of product innovations Modifications of products and process Early adoption of established process j = 5	High order of knowledge of structure	V_5 : High weight $V_5 > V_4$ $K_4 < K_5 > I_5$	$ag_5/h_5 > ag_4/h_4$	υ_5 : Little uncertainty $\upsilon_5 < \upsilon_4$
New 'model' Product differentiation Agency for established innovation Minor technical improvements Late adoption of established process j = 6	High order of knowledge of structure	V_6 : Very high weight $V_6 > V_5$ $K_5 < K_6 > I_6$	$ag_6/h_6 > ag_5/h_5$	υ_6 : Very little uncertainty $\upsilon_6 < \upsilon_5$

The process of development of a technological trajectory discussed above represents a case of a successful trajectory. However, as said before, an innovator can also be surprised by the introduction of a product with better technology, or the research process may show that the relevant ignorance is bigger than it was initially supposed. The innovator's response in this situation will depend on whether the new technology introduced by the competitor and/or the outcome of the research process represents a change on the technological paradigm. A change of the TP will affect not only the weight, but also the knowledge about the structure. There is no alternative for the investor other than to change his/her trajectory. If there is no change on TP, there is no modification on the knowledge about the structure but the weight decreases in any way. In this case, two things can happen: either the innovator allocates more effort on the research process to improve the performance of his/her innovation or he/she changes his/her trajectory.

One important aspect to determine what decision should be made is the position of the innovator inside the trajectory. The further he/she is on the technological trajectory (or the nearer he/she is of phase 6), the more difficult is to change trajectory.

The question to be raised here is the following: In what extent does the use of probable knowledge improve the description of the decision-process related to the introduction of an innovation? Part of the answer has been given before, as it was argued that routines are insufficient to deal with the last act on a problem-solving activity, that is, the final choice in each problem-solving process. However, it remains to be considered the role of probable knowledge (and weight of argument) in dealing with *all* aspects of the uncertainty inherent to the innovative activity.

Although the discussion made so far in this section was mainly concerned with technical and market uncertainties, a full account of the decision to introduce an innovation warrants the analysis of business uncertainty as well. As an investment decision, the introduction of an innovation has to deal with *all* aspects of this decision which are not only affected by technological and market factors, but also by the investors' perception about the economic environment as a whole.

The weight of argument in this case should not be viewed as incorporating only the relevant knowledge and ignorance related to technological and market problems, but also the relevant knowledge and ignorance about *all aspects* that affect the investment decision. In this sense, the increase of technological knowledge about a technological trajectory does not necessarily increase the probable knowledge about the success of the introduction of an innovation if the business ignorance was increased by some other reason. In this case, even when walking along a successful technological trajectory, a decision about the introduction of an innovation may be postponed.

4. Conclusion

We think that the ideas outlined above could represent a possible link between the NS approach to technical change and Keynes's theory of probability. First, the NS approach to innovation stresses the importance of uncertainty as a feature always present in the innovative activity, which 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 shape the routines that are used by the firms.

However, as the uncertainty is never eliminated, routines themselves are not sufficient to explain the decision-making process during the introduction of an innovation. They explain the use 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?

At this point, we have tried to show that Keynes's theory of probability can complete the set of tools required to understand that process. From the use of Keynes's probability it is clear that this process can be seen as rational, despite the fact that one may never know for certain whether the innovation will be a success. The concepts of probable knowledge and weight of argument are the key factors in the understanding of the rationality that is behind the development of a technological trajectory. Routines embody the accumulated knowledge, and they are constrained by the TP. 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 are found becomes more grounded as both weight of argument (state of confidence) and the probable knowledge 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 probable knowledge 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.

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