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On risk, ambiguity, and uncertainty—with a special emphasis on innovation

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Abstract

The objective of this article is to highlight three key concepts in the field of innovation: risk, ambiguity, and uncertainty. To this end, we reviewed the literature to identify the (probability/outcome) pair that helps distinguish these three notions and prevent any confusion. Particular attention is given to the eight types of uncertainty related to innovation, as well as to the various mechanisms available to reduce them. This research also aims to identify the primary source of ambiguity in innovative industries – namely, complexity – while addressing the risks inherent in technological innovation, whether internal or external. Finally, the article proposes an 'uncertainty tree' that synthesizes these various dimensions and situates the three aspects of uncertainty within a process-oriented framework, in order to determine the respective phases in which they emerge.

Keywords: risk, ambiguity, unforeseen uncertainty, radical uncertainty, uncertainty tree, innovation processes.

Résumé

L'objectif de cet article est de mettre en lumière trois concepts clés dans le domaine de l'innovation : le risque, l'ambiguïté et l'incertitude. À cette fin, nous avons mené une revue de la littérature afin d'identifier le couple (probabilité/résultat) permettant de distinguer ces trois notions et d'éviter toute confusion. Une attention particulière est portée aux huit formes d'incertitude associées à l'innovation, ainsi qu'aux différents mécanismes permettant de les réduire. Cette recherche vise également à identifier la principale source d'ambiguïté dans les industries innovantes – à savoir, la complexité – tout en abordant les risques inhérents à l'innovation technologique, qu'ils soient d'origine interne ou externe. Enfin, l'article propose un *'arbre de l'incertitude'* qui synthétise ces différentes dimensions et positionne les trois facettes de l'incertitude dans une perspective processuelle, afin de déterminer les phases respectives au cours desquelles elles émergent.

Mots clés: risque, ambiguïté, incertitude imprévisible, incertitude radicale, arbre d'incertitude, processus d'innovation.

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1. Introduction

Innovation is an editorial phenomenon that has attracted the attention of scholars from diverse disciplines, such as sociology, economics, management, and engineering sciences (Benoit, 2008). The polysemy of innovation complicates its delimitation but, in turn, encourages its application to specific areas. **In economics**, the pioneering work of the prophet of innovation, Joseph Schumpeter, highlights the central role played by technological innovation in the process of the industrialization of the global economy, as well as its contribution to the deterioration of pre-existing economic structures[1]. In the same vein, the mechanism of creative destruction is triggered by the emergence of an innovation that replaces older technologies, thereby legitimizing the transition from one market structure to another (Naqshbandi & Kaur, 2015). In his 1961 book *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*, Joseph Schumpeter emphasized the idea that product innovation enables a company to fully capitalize on monopoly power. Consequently, pricing becomes a strategic decision, made independently of market conditions. Two factors that affect the benefits derived from innovation are product imitation and patent expiration.

The literature review reveals numerous benefits of innovation, including improvements in quality of life, significant increases in economic growth, and wealth creation for nations. The following paragraphs clearly illustrate this reality:

> *'It is well known that some countries grow at a rate much faster than others, even for long periods of time. The most prominent postwar example of a growth success is of course Japan, but other, although less spectacular, examples of persistent differences in growth may also be found among the remaining OECD countries. Outside the OECD area, growth performances differ even more markedly. While a small group of Asian countries appear to have joined Japan in the high-growth club, many other low-income countries continue to be slow growers. How can one account for these differences? The suspicion that it may have something to do with technology has been around for a long time.' (Fagerberg, 1994)*

[1] *Creative destruction is a process of industrial mutation that incessantly revolutionizes the economic structure from within, continually destroying the old one and incessantly creating a new one (Schumpeter, 1942).*

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> *'Governments in a number of industrial and developing nations now view technology policy as an important lever for increasing national income and economic growth.' (Mowery & Rosenberg, 1989)*
>
> *'Informatics and telematics are not just new technologies. Their capacity for being readily integrated into activities is much more important than the speed with which they operate or the volume of information which they handle. It is not just a question of doing things more rapidly but of doing them more meaningfully.'* (*Mahdi Elmandjra, 1989)*

In management, several studies have clearly shown that companies engaging in the implementation and exploitation of product innovations significantly increase their shareholder value. Accordingly, the results of multiple studies underscore the importance of combining incremental and radical innovations to ensure profitability in the short, medium, and long term. This fundamentally points to the vital need to leverage explorations. Despite the vitality of innovation, its implementation remains a challenging endeavor due to the obstacles and difficulties involved in the innovation process. In this context, Philippe Lorino, Professor at ESSEC Business School, states: *"The development of a new product leads to the completion of a specific type of project, generally characterized by a significant degree of technicality and innovation"* (Lorino, 1993). Since its inception, innovation has been characterized by novelty. This inherently means that its unprecedented features often involve elements that are difficult to understand or assimilate, making it a significant source of uncertainty (Kline & Rosenberg, 2009). It is by considering the processual aspect of innovation that uncertainty becomes more pronounced, given that each action is taken under uncertain conditions (Jalonen, 2012). In other words, innovation is a process of confusion through which one ventures into the unknown.[2]

However, the uncertainty associated with innovation can lead to confusion between several concepts, including risk, ambiguity, and radical uncertainty. Each of these key concepts implies a specific management approach; consequently, special attention will be given to clarifying the

[2] *Over the last few decades, uncertainty has emerged as a recurring issue. The literature largely agrees that the lack of information and knowledge about the social environment, coupled with a lack of stability and coherence, defines the decision-making framework of many organizations, particularly in the field of innovation management. Indeed, innovation remains a hypothesis whose truthfulness eludes any certainty. This uncertainty arises from the fact that, on one hand, future events do not necessarily follow the course of past events, and on the other hand, the understanding of the future remains inherently partial (Benslimane, 2023).*

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uncertainty related to the innovation process (Hooge, 2010). In this regard, the purpose of this paper is to address the following inquiry:

On what criteria can the different facets of uncertainty related to innovation be distinguished, how can they be mitigated, and how can they be accurately situated at each stage of the innovation process?

To answer this question, the first section aims to clarify the three facets of uncertainty associated with innovation, namely: risk, ambiguity, and radical uncertainty. After examining the differences between these notions based on the (probability/outcome) pair, the second section discusses the uncertainties related to innovation and explores various approaches to reduce them. The third section meticulously analyzes the notion of ambiguity in the context of innovation, which is largely driven by complexity; therefore, special attention is given to the concept of complexity. The fourth section explains the risks inherent in innovation, specifically internal and external risks. The final section is subdivided into two parts: the first subsection proposes an *'uncertainty tree'* that integrates the three facets of uncertainty previously discussed, while the second subsection positions each facet within a specific phase of the innovation process.

2. An overview of the facets of uncertainty

2.1 On risk, ambiguity, and uncertainty: a conceptual clarification

According to Knight (1921), a distinction must be made between risk and uncertainty. Risk involves a reliable possibility of modeling and calculating probability. On the other hand, uncertainty[3] pertains to an event characterized by a lack of information, meaning that it cannot be subjected to probability calculation or modeling, as demonstrated by the following excerpt: *"But Uncertainty must be taken in a sense radically distinct from the familiar notion of Risk, from which it has never been properly separated...The essential fact is that "risk" means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character; and there are far-reaching and crucial differences in the bearings of the phenomenon depending on which of the two is really present and operating...It will appear that a measurable uncertainty, or "risk" proper, as we shall use the term, is so far different from an*

[3] *The Oxford Dictionary defines uncertainty as a concept about which you cannot be sure. Uncertainty is defined as "doubt or imprecision," "lack of assurance or confidence; hesitation, irresolution," and "something that is neither definitively known nor knowable."*

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unmeasurable one that it is not in effect an uncertainty at all. We shall accordingly restrict the term "uncertainty" to cases of the non-quantitive type."

To distinguish between risk, ambiguity, and uncertainty, various authors refer to the framework of *outcomes and probabilities*. As stated by Knight, risk is characterized by precise knowledge of both outcomes and their associated probabilities (Tversky & Fox, 1995). For example, in the case of a six-sided die, uncertainty lies in not knowing which number will appear, even though all possible outcomes are known prior to rolling the die. Consequently, the probabilities assigned to each outcome are also known (Paju, 2013).

In light of this perspective, an essential question arises: if any component of the *"outcomes and probabilities"* framework is unknown, does it increase the level of uncertainty? Ellsberg (1961) argues that situations in which it is not possible to calculate probabilities or where there is uncertainty regarding the probabilities themselves are termed ambiguous, as opposed to situations where objective probability calculation is possible, which are generally described as risky. Camerer and Weber took a nearly identical view: "*Ambiguity is the uncertainty about probability due to a lack of relevant information… In ambiguous scenarios, probability calculations rely on subjective estimates, which can undermine the confidence in their accuracy*" (Camerer & Weber, 1992).

To better illustrate the specifics of the notion of ambiguity, the example provided by Chow and Sarin (2002) is highly pertinent: *"Before opening a bag of M&M's, we know in advance the colors we will find, but their distribution can only be known after opening the bag."* In the same vein, Boly et al. (1998) specify that in ambiguous situations, uncertainty manifests through the coexistence of two dimensions. The first concerns *"the impossibility of precisely describing events that have not yet occurred,"* while the second *"revolves around the inherent imprecision in our grasp of the facts and our understanding of phenomena."*

As outlined by Loch et al. (2008), situations characterized by detailed knowledge of the outcomes and complete ignorance of the probabilities are classified by Knight as *uncertain* rather than *ambiguous*: *"There is no scientific basis on which to form any calculable probability. We simply do not know. This more challenging situation is referred to as Knightian uncertainty and* sometimes as ambiguity (i.e., the absence of a probability distribution)."

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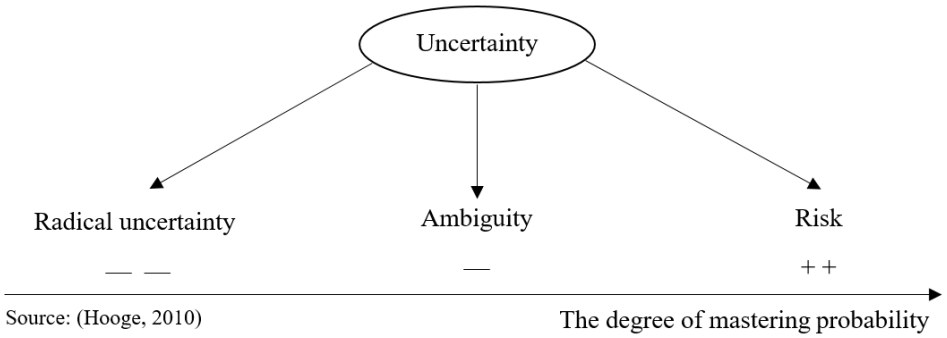
'Keynes without uncertainty is something like Hamlet without the Prince'-this famous quote from Hyman P. Minsky (1978) highlights a fundamental reality that cannot be captured by mere numerical language. In the seventh volume of his work *The General Theory of Employment, Interest, and Money,* John Maynard Keynes referred to the term *'uncertainty'* more than 22 times (Keynes, 2013), describing radical uncertainty stemming from the ever-changing state of the world and the extremely limited cognitive capacities of humans (Lainé, 2016). This leads to a complete lack of information about specific events.

Figure 1: The three facets of uncertainty



In this context, uncertainty encompasses three facets: risk, ambiguity, and radical uncertainty, as shown in **Figure 1**. Each differs based on the reliability of the associated probabilities. Specifically, risk is characterized by a high degree of reliability; ambiguity reflects a more limited or unclear probability; and radical uncertainty pertains to situations where information is absent or incomplete.

2.2 In search of the meaning of unforeseen uncertainty

Meyer et al. (2002) introduced a new facet of uncertainty called ***'unforeseen uncertainty,'*** which represents an intermediate dimension between **foreseen uncertainty** (**ambiguity**) and **radical uncertainty** (**chaos**), as depicted in **Figure 2**. The authors explain that foreseen uncertainty involves identifiable influencing factors for which assigning a precise probability of occurrence is not possible. Moreover, managing foreseen uncertainty requires comprehensive risk management supported by a range of alternative plans. A concrete and exemplary case of foreseen uncertainty can be found in the pharmaceutical sector: *"Pharmaceutical development focuses on detecting and managing risks, primarily concerning the side effects of medications. Developers of new drugs can anticipate potential side effects because these effects have already been observed with related medications. This enables the*

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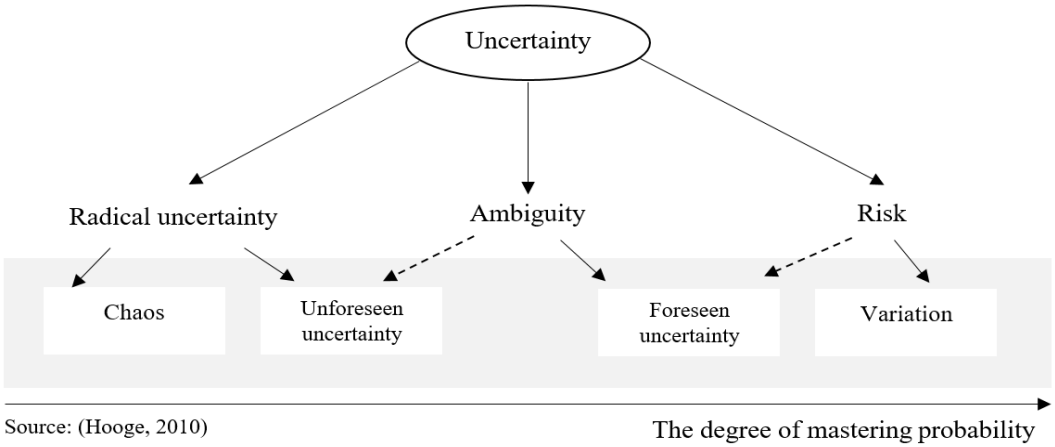
creation of contingency plans to adjust the prescribed dosage or restrict use to specific indications or well-controlled circumstances. The side effect represents anticipated uncertainty. Although the contingency plan may never be used, it is in place should the side effect occur."

Figure 2: De Meyer et al.'s work vs. the three facets of uncertainty



Source: (Hooge, 2010)

Nevertheless, **unforeseen uncertainty** results from the unexpected interaction between several events, each of which could, in principle, be predictable. As a result, the project team may be unable to identify the possibility of the event occurring, or they might consider the event improbable and deem it unnecessary to establish a contingency plan. Additionally, Sommer and Loch (2004) emphasize that unforeseen uncertainty is defined as the inability to recognize and articulate relevant variables and their functional relationships. Engineers often use the term *'unknown unknowns'* to describe this type of uncertainty. Even so, unforeseen uncertainty differs from radical uncertainty, as it can be reduced or understood through human action. For example, judgments, experiences, and ultimately intuition rely on the subject's subjectivity to determine some unknown outcomes. This depends on the situation, learning activities, and experimentation, which aim to provide more objective evidence (Loch et al., 2006).

3. The uncertainty of innovation: problem clarification and solutions verification

3.1 A journey through Harri Jalonen's work

Determining the different facets of uncertainty-such as risk, ambiguity, and radical uncertainty-is essential for effectively managing future events. Additionally, identifying the sources of uncertainty, particularly those related to innovation, is indispensable for the successful implementation of a new product. In a systematic literature review, Jalonen (2012) rigorously

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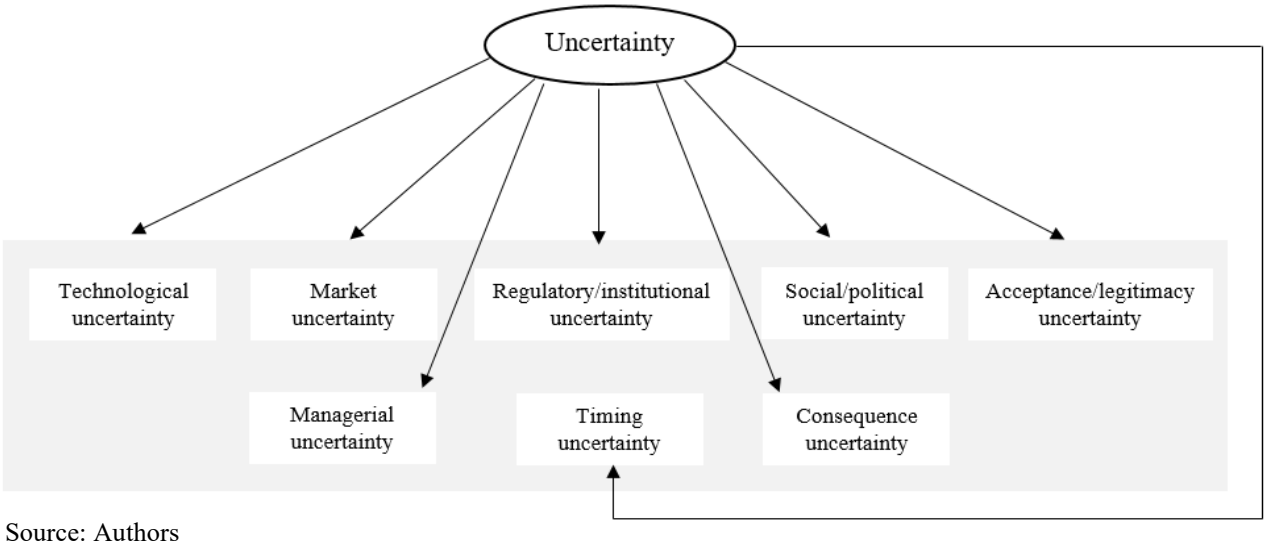
analyzed the concept of innovation-related uncertainty and identified eight categories, as shown in **Figure 3**.

Figure 3: Sources of uncertainty related to the innovation process



Source: Authors

(1) Technological uncertainty: When developing a new product, project managers view technological uncertainty as the potential to utilize a new technology. This technology encompasses the complete range of theoretical and practical knowledge, skills, and artifacts that can be employed to create products and services, as well as production and delivery systems. In other words, technological uncertainty consists of two elements: the technical tools, and the knowledge required to use them. Similarly, the product specifications outline the requirements the product must fulfill, which correspond to the features desired by customers. This necessitates the use of new technologies to create novel products. However, if the technology is found to be newly created, does this impact the level of uncertainty? In this case, the feasibility of the project may be compromised. Technological uncertainty varies with the degree of novelty of the technology used. To put it differently, technological uncertainty increases as the development of a new product requires the use of new technologies. This, in turn, exacerbates other sources of uncertainty and hinders the understanding and visualization of the resources needed for new product development.

(2) Market uncertainty: Innovation and market are closely related terms, and furthermore, one implies the other. Therefore, any innovation disconnected from the market has no value. From this perspective, innovation fundamentally relies on the idea that the invention and

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implementation of technology are aimed at meeting market needs. The market concept we've briefly discussed includes three key components: customer needs, competitor behavior, and the pricing of substitute products. The uncertainty generated by the customer is primarily due to the potential demand for innovation, the elusive and unknown behavior of customers, and, finally, the evolving needs that are uncontrolled and uncontrollable. Consequently, estimating future customer needs is a major challenge. Additionally, market uncertainty also arises from the limited understanding of competitor behavior, as we have highlighted. Innovation relies on the notion that an organization should approach tasks differently than its competitors. Yet, achieving this differentiation is challenging, because the organization cannot be certain of its competitors' intentions.

(3) Regulatory/institutional uncertainty: Institutions and regulations play a fundamental role in driving innovation and reducing the uncertainty it entails. At the same time, uncertainty in institutional and regulatory arrangements often poses a significant barrier, especially given the lengthy and costly administrative procedures that add further complexity and unpredictability. It is also crucial to emphasize the difficulty of implementing institutional and governmental measures to incentivize innovation, as these require a deep understanding of areas that are often opaque to public sector administrators. In this context, the instability of public funding systems could weaken the innovation network. Nonetheless, the uncertainty associated with regulations and institutional arrangements can sometimes benefit innovation. For example, an uncertain regulatory environment creates opportunities in which *"the entrepreneur can create their own rules."*

(4) Social/political uncertainty: To understand the political and social uncertainty related to innovation, it is essential to remember that the innovation process unfolds among various actors and not in isolation. Interactions are vital in activities that require changes in multiple and interconnected components. Nevertheless, these interactions can be a source of uncertainty due to the diversity of interests among the actors involved. This diversity is often seen as detrimental to the innovation process, with cooperation among actors perceived as a risk factor that may increase social and political uncertainty. A wide variety of interactions generates *"fundamental uncertainty"* arising from the personal interests of the actors. Academic research on uncertainty in innovation has deeply explored the issue of social interactions. While some authors argue that reconciling diverse interests could create potential synergy and thus be beneficial for the

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innovation process as a whole, other researchers point out a paradoxical situation. Indeed, when trying to reduce uncertainty, one often engages in relationships with other actors, which can paradoxically lead to a situation of social and political uncertainty.

(5) Acceptance/legitimacy uncertainty: Innovation faces issues related to conflicts of interest, as we have mentioned, but it also encounters cognitive dissonance due to a lack of harmony among members of an organization. This new form of uncertainty is somewhat similar to the previous one, but it stems from the cognitive and sociopolitical legitimacy of innovation. Cognitive legitimacy is essential for acquiring the knowledge necessary to carry out the innovation process, while sociopolitical legitimacy refers to values, norms, and organizational culture. If innovation conflicts with users' expectations and worldview, it could lose its legitimacy. This is why uncertainty related to these concepts adds another layer of complexity when assessing the risk of incompatibility between the innovation and the current thoughts of individuals.

(6) Managerial uncertainty: When presented as a process of transformation, innovation challenges the rational management model. This evokes a process that requires intuitive thinking rather than a structured and rational approach. Due to this, innovation may encounter irrational behavior, which can expose the organization to what is known as managerial uncertainty. Numerous studies have analyzed the nature of thought and the importance of innovative ideas. For example, in order to modify traditional organizational routines, it is important to experiment with ideas. Nevertheless, the significance of innovative ideas depends on the organization's level of resilience. In other words, innovation carries a risk of failure due to unconventional thinking. Managerial uncertainty refers to the search for an effective management model that can frame irrational behavior and the fear of failure. It is therefore pivotal to distinguish between managing routine tasks and managing innovation, which requires more autonomy, less standardization, fewer task restrictions, and a willingness to take risks rather than seek stability. This could lead managers to face control problems while still being in charge, which can be described as a paradoxical situation.

(7) Timing uncertainty: Mastering timing and the speed of action are imposed by global competition. Implicitly, the temporal dimension is inherent in the very definition of innovation as a process. As we have stressed, innovation requires new ideas, where the time factor plays a crucial role. By consensus, time is considered a determining factor for success. In such a

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context, innovation demands quick action, but not too fast! This is where the inherent risk of the temporal dimension of innovation arises. The literature on innovation describes three types of temporal uncertainty. The first refers to the nature of time as a necessary factor for acquiring new knowledge (taking enough time is required to deepen our understanding). The earlier we act, the greater the uncertainty. The second type refers to the gradual and progressive increase of temporal uncertainty as the phases of an innovative project unfold. During the early phases of a project, the degree of temporal uncertainty is not considered a problem; however, as the work progresses, an increasing number of individuals become involved, which represents a source of potential risk and can be described as problematic. The third type, in turn, refers to the introduction of the concept of *"temporal complexity."* This concept suggests that time should be viewed as a social construct with multiple dimensions. To understand the nature of time in the context of innovation, it would be preferable to distinguish its different components. Temporal complexity is associated with various elements of time and should be perceived as a factor of uncertainty for innovators.

(8) Consequence uncertainty: Since it is difficult to predict the impacts of innovation, it is seen as a source of uncertainty arising from the unpredictability of expected outcomes. Therefore, a degree of uncertainty exists if the relationship between inputs and outputs cannot be accurately established. Three dichotomies should be considered in the consequences of innovation: direct and indirect consequences, desirable and undesirable consequences, as well as anticipated and unforeseen consequences. Consequences are classified as direct when they represent an immediate response to innovation. Otherwise, they are indirect, in the sense that the response is considered second-order and only manifests once the immediate consequences have occurred. As for desirable effects, they refer to operational impacts, while undesirable consequences are defined as impacts related to dysfunctions caused by innovation within a social system. Anticipated consequences indicate expected effects, while unforeseen or unexpected consequences refer to the unrecognized impacts of innovation.

3.2 Critical solutions to reduce uncertainty

After briefly outlining the various sources of uncertainty in the innovation process, we now turn to proposing effective practices to mitigate them. We begin with technological uncertainty, which comprises two key elements: the technical tools and the knowledge required to operate them. Firstly, to deepen our understanding of a specific field of activity, Michel Pendaries and

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Hector Castaneda propose several solutions in their article entitled *« Comment piloter la performance du transfert de connaissances dans le processus d'innovation des entreprises technologiques »*, notably: (1) Recruit a new employee skilled in the explored field of activity, to train existing staff and provide the company with the necessary knowledge; (2) Cooperate with other organizations to quickly reduce the gap between what is known and what is not; (3) Establish R&D alliances with the aim of identifying and gathering resources and skills that the company does not possess; (4) Resort to subcontracting to quickly access expertise already developed by others (Pendaries and Castaneda, 2013). Secondly, numerous questions arise with equal relevance and urgency concerning the technical aspect, in particular: *Are there technological solutions? If so, are they reliable? Efficient? And within acceptable cost limits in a competitive market?* (Hooge, 2010).

Secondly, as previously emphasized, market-related uncertainty fundamentally depends on three key elements: customer needs, competitor behavior, and the price of substitute products. On the one hand, to identify customer needs, companies rely on close and effective collaboration between marketing teams and R&D engineers. Nevertheless, there is nothing to prevent a new technology, commercialized by competing firms during the development phase, from significantly influencing customer expectations and experiences-potentially leading to the rejection of the product under development. In light of the above, although customer needs can be identified through market research, there is no guarantee that these needs will remain stable over time (Benslimane, 2023; Benslimane & Benjelloun, 2023; Benslimane & Benjelloun, 2025a; 2025b; 2025c). This reflection raises many additional concerns, such as: *What price would the customer be willing to pay for this product? What sales volumes can be reasonably anticipated? What is the estimated cost of its design? What will be the associated manufacturing cost? Is there a sufficiently large customer base willing to accept the price necessary to ensure satisfactory profit margins? Are we capable of designing and then manufacturing this product at a cost lower than the revenue it is expected to generate?* (Hooge, 2010). On the other hand, competitor behavior gives rise to significant considerations: *Does the product (or service) offer a genuine opportunity for market differentiation? What are the likely catch-up times for competitors? Is it strategically wise to position ourselves as a market leader, or is it more appropriate to adopt a follower strategy by entering an already established market?* (Hooge, 2010).

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Thirdly, to address regulatory and institutional uncertainty, it is essential to reduce the complexity of the institutional arrangements to facilitate the diffusion of innovation. Public sector administrators are therefore encouraged to enhance their understanding of emerging industries. This improved understanding will help prevent the establishment of an unclear regulatory environment in the future, while enabling entrepreneurs to operate in a more favorable context without having to create their own rules. Finally, the stakeholders involved in innovation, particularly the innovators, must stay informed about potential changes that could affect regulation and the institutional arrangements. Beyond the aforementioned solutions, numerous equally pertinent matters persist, including: *Do existing laws allow for the introduction of this innovation to the market? Are there any regulatory or para-regulatory requirements specific to the field targeted by the innovation? Do we have any information regarding potential changes in regulations or standards that could hinder the commercialization of the innovation?* (Hooge, 2010).

Fourthly, it is widely recognized that innovation arises through dynamic interactions among diverse stakeholders, reflecting a multiplicity of interests within the organization and illuminating its inextricably political and social dimensions. As such, the innovation process demands continual attentiveness to organizational goals, alongside a deliberate effort to harmonize individual aspirations with shared objectives. To deal with this situation, top management is obligated to find answers to the subsequent concerns: How can we effectively identify and map the interests of all key stakeholders involved in the innovation process? What mechanisms can we put in place to ensure regular, meaningful dialogue among diverse stakeholder groups? How can we ensure that individual goals and motivations are aligned with the broader organizational vision for innovation? What incentives or frameworks can encourage collaboration and shared ownership of innovation outcomes? What strategies can we use to navigate internal power dynamics that may hinder innovation efforts? How can we monitor and adapt innovation efforts to remain responsive to evolving stakeholder needs and organizational priorities?

Fifthly, in responding to intrinsic uncertainty surrounding the legitimacy and acceptance of innovation, it is crucial to consider the existing knowledge and perceptions of prospective users, as these often underpin resistance to change. To mitigate this, a well-crafted action plan should be implemented to enhance users' understanding and appreciation of the innovation, thereby

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fostering smoother adoption and broader acceptance. Moreover, it must be recognized that innovations misaligned with personal values or prevailing organizational norms are particularly prone to rejection. Hence, it becomes essential to ensure that innovation is thoughtfully aligned with individual values, that all relevant stakeholders are engaged from the outset, and that communication and transparency are prioritized throughout the process. Equally important is the need to cultivate an adaptive managerial culture and to rigorously evaluate the innovation's impact prior to, any large-scale implementation.

Sixthly, by nature, innovation is a stochastic activity, unlike routine tasks, which rely on established norms and standards designed to enforce strict control mechanisms. Innovation, synonymous with the unknown, demands greater flexibility, autonomy, and risk-taking. Consequently, control should emphasize the social aspects and values within the organization. Embracing this perspective helps to reduce managerial uncertainty. Similarly, in our study ***Re-writing Management Control Philosophy***, we assert that the degree of novelty in innovative projects profoundly influences the nature of management control. Indeed, as the level of radicality intensifies, there is a growing reliance on social controls, such as interactive and boundary systems-to navigate the extensive uncertainties involved. Beyond identifying the optimal control system for any given innovation, it is pivotal to recognize that each phase of the innovation process possesses unique characteristics, necessitating a tailored approach to management control (Benslimane & Benjelloun, 2025).

Last but not least, to reduce uncertainty related to timing, several actions are necessary: (1) Recognizing and seizing opportunities as early as possible to ensure a rapid market introduction; (2) Understanding and accepting that the initial phase of the innovation process is characterized by a high level of uncertainty, which progressively decreases as knowledge increases throughout the process; (3) Moreover, this uncertainty is particularly pronounced at the beginning because only a limited number of participants are required to confront the situation directly. Finally, in the case of uncertainty related to consequences, two scenarios arise: (1) So far, no method or tool has been able to reliably predict the relationship between the inputs and outputs of the innovation process. (2) The uncertainty associated with the complexity of innovation can be partially reduced through managers' subjective assessments.

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4. Ambiguity, complexity and innovation

4.1 What is the complexity of complex systems?

Uncertainty cannot be properly addressed without invoking the concept of complexity. Indeed, the innovative product is a complex system, and this complexity is due to the number of its components and their interactions. In the same vein, Hooge (2011) specifies that the profusion of elements that make up the product, as well as the random and unpredictable interactions that link them, can sometimes give rise to unexpected outcomes. To put it another way, the complexity of the system represents the major issue encountered by both internal and external actors, which revolves around the meticulous understanding of the multiplicity, plurality, and interactivity of the system's elements. In alignment with this view, the literature on this topic highlights the various generic decompositions of complex systems, which are characterized by complexity of diverse nature, particularly in the context of large industrial groups, such as products, processes, skills, coordination, the canonical model, etc.

Understanding a complex system is a difficult task; however, this situation can change by reducing the level of uncertainty related to complexity through the collection of information about the elements that constitute it. According to Simon, the complexity of the plurality of actors and their interactions does not, under any circumstances, create uncertainty, but rather results from the limitations of the human brain: *« Analysis of their behavior [of complex systems] would involve such detailed knowledge and calculation of the interactions of their elementary parts that it would be beyond our capacities of memory or computation. »* (Simon, 1962).

Georges Henri Lewes is the first author to have touched upon the concept of emergence in his scientific publications dating back to 1875, which aim to characterize another dimension of complexity by addressing the system's ability to deviate from its initially planned mode of operation: *« Emergence is the concept of some new phenomenon arising in a system that wasn't in the system's specification to start with. »* (Standish, 2001).

4.2 Forms of complexity and their transposition in innovation

Complexity takes two forms: random and organizational. Random complexity is *'related to the difficulty of describing a system with the shortest possible algorithm'*, while organizational complexity *'concerns the number of rules governing the functioning of the system'*. In his article,

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" La profondeur logique de Bennett," Delahaye provided a concrete example describing a house to clarify the difference between the various forms of complexity: *« The floor plan of the house corresponds to the organized complexity of the house. However, this plan does not specify the exact details of the plaster design on the walls. The complete description of the house, which should include all the details of the plaster, contains much more information than the floor plan. The house has a moderate level of organized complexity (a floor plan is not very complicated) and a relatively high level of random complexity. »*

Sophie Hooge's thesis titled *'Performance de la R&D en rupture et des stratégies d'innovation: Organisation, pilotage et modèle d'adhésion'* emphasizes that the complexity of the automotive industry manifests in two forms: organized complexity, which is reflected in *'the design and optimization process, job descriptions, the hierarchical structure, and finally supplier contracts, etc.,'* and random complexity, which revolves around 'the technical difficulties of designing parts, their connections, *their interactions, and ultimately the human behaviors underlying the design activities.'*

In light of the above, the complex system reveals itself as a living organism, endowed with its own autonomy. Not only is it difficult to fully comprehend, but it also possesses the ability to transgress its own operational rules in order to adapt smoothly to the ecosystem in which it evolves. Edgar Morin refers to this particularity of the complex system as *"auto-eco-organization."* This ability undeniably presents an additional challenge in the quest to master such a system; nevertheless, it also paves the way for innovation and the continuous adjustment of design choices in response to new information.

Innovation transforms the characteristics of a product or process, and sometimes even disrupts what once seemed to be its very essence (main function, design, etc.). In doing so, it destabilizes the established references of the group responsible for the design, leading to the obsolescence of design processes, the redefinition of roles, and the devaluation of expertise. Each layer of the complex system, whether it be the product, the process, or the skills, is weakened by the introduction of innovation. Thus, managing innovation within a complex system, due to our limited understanding of interactions and the system's self-organization, involves additional dimensions of uncertainty compared to a project focused on a simpler object (Hooge, 2010).

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5. On the risks of innovation

5.1 External risks, with a special emphasis on innovation

The Oxford Dictionary defines risk as *"the possibility of the occurrence of an unpleasant event."* The article by Aven and Renn, titled *"On risk defined as an event where the outcome is uncertain,"* follows the same line of thought, reviewing a multitude of definitions proposed by scholars. This leads to the conclusion that risk encompasses several meanings, including **probabilities**, **expected value**, **events/consequences**, and **uncertainties**. The implementation of innovation projects is not solely conditioned by the management of uncertainties; their success also depends on risk management. Andrew Lee-Mortimer's publication, *"Managing Innovation and Risk,"* is central to these considerations, while noting that: *"To ensure the success of innovation and guarantee its translation into successful products, the inherent risks must be managed effectively from the beginning of the innovation process."* (A. Lee-Mortimer, 1995).

It is important to emphasize that companies must address two types of risks: internal and external. The first category of risks encompasses four main types:

(1) Physical risk: This can be illustrated by numerous examples. Firstly, new medications carry physical risks because they are designed to affect the human body. Secondly, consumers may hesitate to use new hair colors out of fear of causing permanent damage.

(2) Economic risk: This highlights that the higher the cost of an innovation, the greater the perceived economic risk. For example, goods that rely on advanced technologies, such as laptops and video cameras, face potential risks because many consumers delay their purchases, hoping to obtain a better product-price ratio later on.

(3) Functional risk (also known as performance risk): This type of risk concerns the reliability of the innovation and raises several questions: Is the newly created product well-tested? Is it truly reliable?

(4) Social risk: This refers to the fear that customers may experience social ostracism or ridicule from their peers when adopting an innovation. For example, buying generic foods from a luxury brand is considered unacceptable by most people (Ram and Sheth, 1989).

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5.2 Internal risks, with particular focus on innovation

The **second category** of risks includes the risk related to **quality**— *"the risk of not meeting the customer's needs,"* **cost**—*"the risk of exceeding the allocated budget,"* and finally, **schedule**—*"the inability to complete the project within the allotted time"*. Building on the work of Lee-Mortimer (1995), some projects become editorial phenomena that capture headlines in the national and international press, while many others numbering in the thousands fail less dramatically due to budget overruns. A survey conducted by PA Consulting of British companies engaged in new product development revealed that:

- 40 percent of companies reported that more than half of their projects exceed both the allocated budget and the assigned time.
- 50 percent of respondents have a recent project that exceeded the budget by more than 100 percent.
- 66 percent of companies have a recent project that fails to meet or adhere to the trifecta of cost, quality, and schedule.

The question that now arises, with equal parts fairness and urgency, is the following: if an innovation project fails to manage one of the previously mentioned risks, does that constitute a true failure? In their book Reinventing *Project Management: The Diamond Approach to Successful Growth and Innovation*, Shenhar and Dvir argue that the modern world has witnessed the emergence of projects which, despite failing to meet assigned deadlines or allocated budgets, have been regarded as significant achievements for humanity. Conversely, many projects have failed despite adhering to schedules and budgets. This can be explained by the absence or even destruction of value for the clients or organizations involved. The next passage clearly illustrates the arguments put forward by the two authors: *'Before introducing its big hit, the Macintosh, in 1984, Apple Computer completely failed with its predecessor, the Lisa computer. Apple's managers acknowledged later that without the lessons learned and technologies developed on the Lisa project, the Mac's success would not have been possible—bringing into question whether Lisa was indeed a complete failure.'* (Aaron J. Shenhar et al, 2007).

As reported by Erling S. Andersen, the obsolescence of the iron triangle can be attributed to the growing interest in the concept of the responsible (or civic-minded) enterprise, the

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increasing focus on knowledge as a competitive advantage, and, finally, the turbulence of the current environment. As a result, projects have shifted from a short-term vision to a long-term approach aimed at improving the economic, social, and environmental conditions of stakeholders.

6. Discussion

6.1 Unveiling the facets of innovation-related uncertainty

By carefully analyzing the anatomy of uncertainty, we find that it is comparable to that of a tree. In this analogy, the roots, buried in the ground, represent the central concept under examination, namely uncertainty. These roots (uncertainty) nourish different facets: risk, ambiguity, and radical uncertainty. Ipso-facto, our tree consists of only three branches, each representing a clearly defined facet of uncertainty, as can be seen in **Figure 4**. The first branch, which outlines the risks associated with an innovation project, consists of two twigs. The first twig symbolizes internal risks and is composed of three smaller twigs, respectively reflecting a dimension of internal risk: cost, time, and quality. The second twig denotes external risks related to the innovation project, in particular social, economic, functional, and physical risks, every risk corresponds to a smaller twig[4]. The second branch stands for ambiguity and has a single twig that demonstrates complexity. This twig is formed by three smaller twigs, as the complexity inherent in an innovation project is closely connected to the nature of the adopted strategy, the implemented product, and the process[5].

The third branch is indicative of radical uncertainty and comprises eight twigs. Three of these twigs illustrate three types of uncertainty: timing uncertainty, consequence uncertainty, and market uncertainty. Each of these twigs is made up of three smaller twigs, with respective smaller twig expressing a clearly defined element of one of the aforementioned types of uncertainty arising from innovation. The final five twigs are meant to depict subsequent uncertainties: social/political uncertainty, managerial uncertainty, regulatory/institutional uncertainty, and uncertainty related to acceptance or legitimacy. Each of these twigs is conceived from two smaller twigs, with every smaller twig indicating a clearly defined element of one of the previously mentioned sources of uncertainty related to innovation.

[4] Consequently, the second twig comprises four smaller twigs.
[5] From the above, any given cause of complexity is manifested as a smaller twig.

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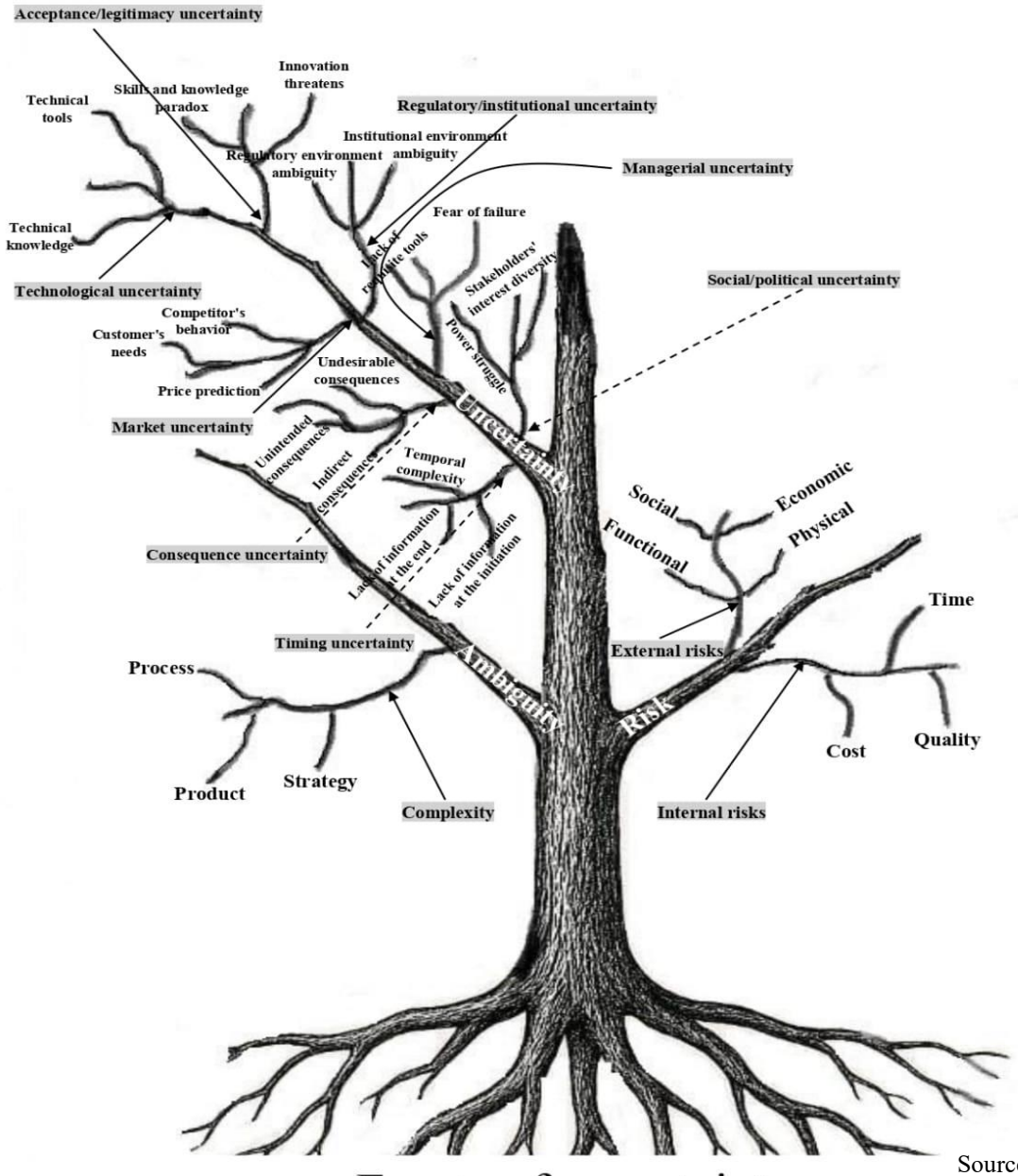
Figure 4: Facets of uncertainty related to innovation



Source: Authors

6.2 Exploring the facets of uncertainty in the innovation process

Placing the various facets of uncertainty within a processual perspective is essential for linking each one to a specific phase of the innovation process. This approach facilitates the development of appropriate intervention tools to mitigate these uncertainties. First, we will identify the main sources of uncertainty related to the innovation process. Next, we will

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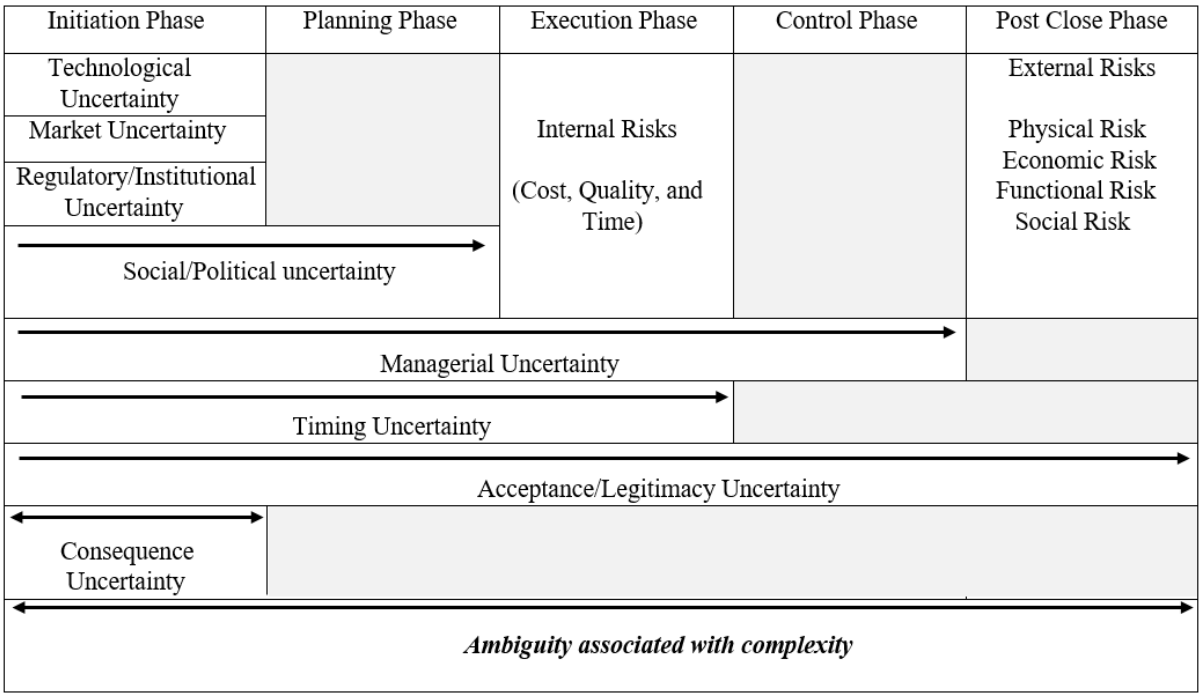
examine the role of ambiguity within this process, and finally, we will conclude with an analysis of internal and external risks from a strictly processual perspective, as illustrated in **Figure 5**.

Figure 5: Facets of uncertainty during each stage of the innovation process



Source: Authors

As outlined in Section 2, innovation is shaped by eight distinct sources of uncertainty. The first three-technological, market, and regulatory uncertainties-are particularly critical during the initiation phase. At the outset of any innovation process, organizations are confronted with major, often irreversible decisions concerning the availability of key technologies, the existing expertise within their teams, and prevailing market dynamics. Typically, a preliminary assessment is conducted to gauge customer needs and analyze competitor strategies. Yet, it is crucial to recognize that any move by a competitor may swiftly reshape customer expectations. In parallel, innovators must carefully navigate the legal landscape to ensure that no regulatory constraints impede the development or commercialization of the envisioned solution.

Social and political uncertainty, comparable to technological, market, and regulatory uncertainties, arises at the initiation phase but, uniquely, continues to influence the planning phase. Emerging from the interactions of various stakeholders, this uncertainty is driven by the organization's multifaceted interests. It is most pronounced within the first two phases, gradually subsiding as qualitative and quantitative objectives are crystallized, reducing the risk of opportunism.

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Expanding the scope further, managerial uncertainty extends across all phases of the innovation process, specifically initiation, planning, execution, and closure, excluding only the post-closure stage. It stems from the management approaches employed to address the inherently unique and evolving nature of innovation, tailored to the specific demands of each phase. This form of uncertainty is both expected and necessary, as effective innovation management calls for autonomy, flexibility, risk-taking, and the capacity to navigate unplanned tasks. Such requirements are rooted in the stochastic character of innovation, which stands in stark contrast to the predictability of routine management.

In addition, temporal uncertainty pervades the entire innovation process, with the exception of the fourth and fifth phases. This can largely be attributed to the progressive accumulation of knowledge, which gradually reduces uncertainty as the process advances. However, this dynamic tends to hold true primarily for incremental innovation. In comparison, radical innovation remains marked by persistent uncertainty, as reflected in its notably high failure rate.

Before turning to the final point, it is essential to underscore that uncertainty surrounding acceptance and legitimacy permeates every stage of the innovation process. This form of uncertainty originates from the potential for innovations to challenge users' existing skills and knowledge, while also posing a threat to individual values and established organizational norms. Its persistence throughout the process is further explained by the presence of distinct stakeholders at each phase, each expected to adopt or engage with the innovation in a specific capacity.

The final source of uncertainty referred to as consequence uncertainty emerges during the initial phase of the innovation process, as it results from a limited understanding of how inputs translate into outcomes. This gives rise to ambiguity not only regarding the interactions among the system's components but also concerning the broader societal implications of the innovation.

After tackling the various sources of uncertainty inherent in the innovation process, the true ambiguity of innovation emerges from its intricate multidimensionality-spanning strategy, process, product, and customer spectrum. Strategically, the simultaneous presence of multiple products complicates the task of prioritization and alignment of vision. The innovation process itself unfolds through a sequence of stages, each engaging diverse stakeholders and generating a rich yet challenging flow of information to manage. Product complexity arises from the integration of numerous components, whose interplay can yield unforeseen outcomes. Lastly,

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the heterogeneity of customer profiles amplifies the difficulty of monitoring and heightens the uncertainty in tailoring offerings to ever-evolving market expectations.

Finally, the fourth section elucidated that innovation risks bifurcate into two principal categories: internal and external. Internal risks encompassing cost reduction, time efficiency, and quality enhancement, manifest predominantly during the execution phase, a reality extensively documented in scholarly discourse. These risks rest chiefly with operational teams, who endeavor to mitigate them through refined management practices such as the Kaizen philosophy. Conversely, external risks classified into economic, social, functional, and physical dimensions-reside at the heart of the final stage, reflecting the fundamental reasons behind users' reluctance or refusal to embrace innovations.

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7. Conclusion

A literature review has shown that the uncertainty associated with innovation has three facets, based on the outcome/probability pair, namely: risk, ambiguity, and uncertainty. Each of these facets requires an appropriate intervention mechanism to be properly managed and, consequently, reduced. While internal risks require management tools, such as the use of management control instruments, complexity relies on managers' subjective estimates to solve the puzzle of the proliferation of components constituting a system, as well as the unpredictable results of interactions between these components. The uncertainty stemming from innovation can sometimes be managed by gathering information, asking questions, or involving external stakeholders with specialized knowledge in a given field. However, in some cases, uncertainty cannot be reduced through these means. In such situations, it becomes necessary to live with it- or even temporarily ignore it-since, over time, knowledge accumulates and uncertainty tends to diminish. To address the different facets of uncertainty, it is not enough to merely identify them and determine appropriate intervention mechanisms. It is also important to situate them within a process perspective, identifying when they emerge during specific phases of the innovation process, to encourage a more proactive approach.

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