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Influence of Risk on Innovation: Inertia Strategies in the Space Industry

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We try to confirm the hypothesis that the higher the level of technological uncertainty and the higher the cost of breakdowns in space products the more space organisations will adopt intensive inertia strategies.

Inertia strategies are innovation strategies that integrate the risks associated with technical change thanks to the principle of risk aversion. In an attempt to ensure high levels of reliability, these strategies lead to the slowing down of innovation dynamics. The introduction of inertia strategies helps to reconsider the situations of technical inertia in risky contexts.

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Keywords

Innovation; Risk; Inertia strategies; Reliability; Evolutionary approach; Space industry.

1 Introduction

In a reference manual on innovation, Tidd, Bessant and Pavitt (2006) refer to the fact that 72% of product innovations are failures. This statistic underlines the fact that the majority of the innovative activities conducted by organisations fail. Any activity with such a poor rate of success is necessarily regarded as very risky, and the organisations keen to implement are likely to be influenced by the general principal of risk aversion. In other words, it would be normal to assume that organisations would avoid some of these risky activities in order to ensure their survival.

While these general considerations on the influence of risk are familiar, it is interesting that they tend to be overlooked in the literature on innovation. Uncertainty is a major feature of innovations studies, and concepts such as trial and error, search, and learning are used to integrate it. However several scholars underline at the same time that because of a "pro-innovation bias [...] much innovation research tends to stress that innovation benefits its producers and users, and simultaneously ignores the risks of the associated change processes" (Meeus and Oerlemans, 2000, p. 42). Carroll and Teo (1996, p. 620) underline that this situation also prevails in popular evolutionary studies in which "change is frictionless, relatively cost free and without major risk".

This paper is an attempt to face this limitation in innovation literature. More precisely, we want to analyse the influence of risk in the innovation strategies implemented by organisations. Risk is analysed by combining two main approaches: decision theory and risk management (March and Shapira, 1987). We combine the evolutionary perspective proposed by Nelson and Winter (1982) and the approach proposed by Hannan and Freeman (1984) in order to study innovation. Based on these theoretical frameworks, we build a model from which to argue that high levels of technological risk lead organisations to implement inertia strategies. These are a type of innovation strategies that integrate the principle of risk aversion by favouring high levels of technical reliability and reuse of the technologies validated. Based on studies of complex products and systems (CoPS), and high reliability organisations, we test our model on the space industry (Hobday, 1998; Davies and Hobday, 2005; Vaughan, 1990; Roberts, 1990; Rochlin, 1996; Demchak, 1996). These authors show that space organisations manufacture innovative products and face high levels of technological risk. We validate our model by testing the hypothesis that the higher the level of technological uncertainty and the higher the cost of breakdowns in space products the more space organisations will adopt intensive inertia strategies. We conduct econometric regressions based on a dataset composed of a sample of 573 technologies used by a major prime contractor in the European space industry.

Section 2 presents the theoretical framework and links the issue of risk to the topic of innovation. Section 3 presents the model and Section 4 describes the empirical framework, which is the space industry. In the Section 5, we test the model after describing the construction of the independent and dependent variables used in our estimations. In Section 6, we discuss the results and present some implications of the concept of inertia strategies.

2 Linking Risk and Innovation

2.1 Approaches to Risk

There are two main approaches that can be used to analyse the issue of risk: decision theory and risk management approach (March and Shapira, 1987). Both retain the general principle of risk aversion, implying we would be sure of receiving 100 than to enter a lottery in the hope of receiving 1 000 but with a low probability.

However, despite adherence to this principle, decision theory and risk management are two very different approaches to the topic of risk which tend to be quite independent. Comparing a choice considered risky for each illustrates this situation. In decision theory a risky choice is a choice with a large range of possible outcomes, in risk management, a risky choice is a choice that could result in important losses (March and Shapira, 1987).

In this paper, we draw on the risk management approach although we incorporate some aspects of decision theory.

2.1.1 Decision Theory

Decision theory emerged in 1921 with the seminal book of Knight entitled *Risk, Uncertainty and Profit*. Here, the word "risk" describes both a measure of the distribution of possible outcomes from a choice and a specific situation in which there are unique objective probabilities for each choice. The approach is aimed at identifying the probabilities of the occurrence of every possible outcome in order to know which will occur. The use of a set of formal tools helps to identify the event that has the highest chance of occurring out of all possible events. These events usually have two main elements: a probability of occurrence and the associated gains/losses. Decision theory has been implemented successfully by economic studies in areas such as lotteries, finance, and insurance (Jeffcoat, 1989; Kelsey and Quiggin, 1992; Miller, 1998).

2.1.2 The Risk Management

The risk management approach handles the concept of risk quite differently. Here, the word "risk" refers to a hazard that implies a cost. The risk management approach is generally interested in identifying the causes of a risk. As the number of risk causes that can be identified may be almost infinite, this approach analyses a large number of risks, the most important being political risk, economic risk, sociocultural risk, and technological risk. Unlike decision theory, risk management includes more heterogeneous studies which can be grouped in two categories: the disaster studies branch (Perrow, 1984; Roberts, 1990; Weick and Roberts, 1993) and the risk analysis branch (MIL-HDBK-217E, 1986; Cooper and Chapman, 1987; Short and Rosa, 1998; Evans et al., 2002; Chapman and Ward, 2003).

The objective of disaster studies is to understand the incubation processes of hazards. This is enabled by works in sociology, psychology and management. One of its more important results was the idea of the influence of man-made disasters (Vaughan, 1990). The objective of the risk analysis studies is to measure the risk associated with each choice, in order to able to choose the least risky option. This group of studies incorporates several tools provided by formal works in engineering and biology, and suggests that losses cannot always be expressed in monetary terms. They may comprise days of lost production, volumes of lost raw materials, loss of human lives, or days of illness.

2.2 Evolutionary Theories of Innovation

In order to demonstrate how the issue of the risk is integrated in the topic of innovation, we focus on the evolutionary approach because it aims at analysing change and it is currently popular in innovation studies. We divide this approach into two main perspectives: the adaptation perspective (Nelson and Winter, 1982) and the selection perspective (Hannan and Freeman, 1984).

2.2.1 The Adaptation Perspective

The adaptation perspective dominates the evolutionary studies on innovation. It is sometimes referred to as the *pro-change perspective* (Schwarz and Shulman, 2007), the *rational adaptation theory* (Beugelsdijk et al., 2002).

The starting point of this perspective is the assumption that organisations face changes in the environment by adopting adaptation strategies. Organisations are able to adapt to new contexts by acting on their strengths and weaknesses in satisfying ways.

Adaptation strategies are always the result of a change in organisation's routines, and can be achieved in three main ways. An organisation may change when it reorganises existing routines in a new way, or imitates the routines of other organisations or when it creates new routines based on search (R&D is a type of search). Because these three ways to change help the organisation to face changes in its environment, the adaptation perspective assumes that adaptation strategies reduce organisational mortality.

2.2.2 The Selection Perspective

The selection perspective is less popular for the study of innovation and is sometimes referred to as *ecological theory* (Singh et al., 1986) and *structural inertia theory* (Kelly and Amburgey, 1991).

The starting point of this perspective is the assumption that an organisation is not able to act on its strengths and weaknesses in a satisfying way. In other words, an organisation does not face changes in its environment because it has found a way to adapt to a new context. The organisation faces changes because it enjoys the features required to survive. Organisations do not adapt to but rather are selected by their environment.

We can illustrate the relevance of this rationale with the concept of destructive creation. Destructives aspects emerge following radical innovations because some organisations are not able to adapt to the changes induced by these innovations.

The second part of the rationale for the selection perspective is the assumption that modern economies display high levels of uncertainty which implies errors are frequent and may endanger the survival of organisations. Within this context, the environment favours organisations with high levels of reliability and accountability, and scholars argue that these two features are required for an organisation to survive. Since the easiest way to achieve and maintain high levels of reliability and accountability is to reproduce their structures, the selection perspective argues that structural inertia helps organisations to survive.

2.3 Evolutionary Theories of Innovation and Risk

The adaptation perspective integrates the issue of uncertainty by assuming for instance that the outcome of the search conducted by organisations is difficult to anticipate. However, it does not recognise that the issue of search may induce a negative outcome which may endanger the organisation survival. As mentioned by Meeus and Oerlemans (2000, p. 42) "Due to its pro-innovation bias and its adaptationist perspective much innovation research tends to stress that innovation benefits its producers and users, and simultaneously ignores the risks of the associated change processes". According to Carroll and Teo (1996, p. 620), in this perspective "change is assumed frictionless, relatively cost free and without major risk".

This situation can be viewed from several angles. First, the adaptation perspective links innovation to progress (Nelson, 1995). As a result, in the long term, the outcome of innovation is assumed to be higher than the global cost of the errors incurred during the innovation process. Second, Murmann, Aldrich, Levinthal and Winter (2003) mention that "In the models, firms have no difficulty in replicating their routines either in time or in space". If the routines used to ensure successful innovations are reproduced cost free this implies that the occurrence of failures during the innovation process is very low. Finally, there is the way that the concept of innovation is used: a product innovation is a successful invention while a product-innovating organisation is an organisation that simply implements new products. If we assume that an innovation is always a success, but if we label innovative organisations without any reference to success or failure, we create a confusion that may lead to neglect innovation activities that imply risk (Carroll and Teo, 1996; OECD, 2005).

The selection perspective is more useful to analyse the influence of risk in innovation because their starting point are high levels of uncertainty in modern economies. This uncertainty implies that organisations may make major errors which endanger their survival. Since change is regarded as risky, this perspective argues that the environment selects organisations with high levels of reliability and accountability, and ends by considering that organisational inertia favours survival. The selection perspective introduces an interesting link between risk and change.

However, this perspective has several limitations which need to be overcome. It retains a selection standpoint in which organisations are not able to increase their strengths or reduce their weaknesses in order to cope with changes in the environment. As organisations are not able to adapt to their environment, they cannot formulate a relevant strategy. This is an important limitation because our objective is to underline the existence of efficient innovation strategies that integrate risk. Also, the selection perspective focuses on organisational change while we are interested in technical change.

Because both perspectives display limitations and relevant aspects, we decided to combine them to construct our model.

3 The Model

In order to combine the adaptation and selection perspectives, we focus on technological risk and the principle of risk aversion. This type of risk is close to the concept of technological uncertainty proposed by Rosenberg (1982). According to Rosenberg, there is an increase in the uncertainty related to the performances of technical systems when organisations innovate: first, because it is difficult to anticipate the impact of the novelty on the entire system, and second because there is a lack of knowledge regarding the properties of the new technologies. As a result, we assume that technological risk refers to technical breakdowns, and we describe it in terms of the cost and occurrence of such breakdowns.

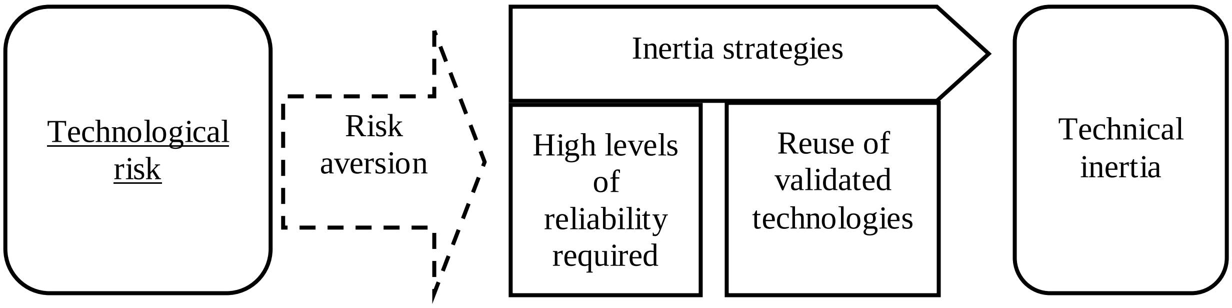
Within this context, the risk aversion principle implies that among equivalent technologies in relation to their technical performance, cost, delivery time, etc., the less risky choice is the most reliable technology. This formulation of the risk aversion principle is not totally appropriate to the topic of innovation because organisations do not know whether they are facing equivalent technologies. Because the technology is new, organisations tend to lack knowledge about effective technical performance, for example. This may lead the organisation to choose a less reliable technology because it claims to offer higher technical performance. Thus, we will assume that the level of technological risk varies.

This allows us to argue that the higher the level of technological risk the more organisations are willing to choose the most reliable technologies even when competing technologies are seen as have “better” features. In other words, the increased level of technological risk gives importance to technical reliability and reduces the significance of features such as technical performance, cost, and delivery time.

This rational behaviour is the first step in a process that ends with the development of technical inertia. Indeed, when technological risk is high the easiest way to maintain high levels of technical reliability is to favour the reuse of the validated technologies. If a technology has demonstrated its reliability in previous use, its reuse should produce the same level of reliability. This principle favours the exclusion of new technologies from the technologies used by the organisation and results in the development of technological inertia with the organisation employing fewer and fewer new technologies. Because the strength of this process is function of the level of technological risk we can say that the level of technical inertia is a result of the level of technological risk.

This process describes the content of inertia strategies which we define as innovation strategies that integrate the risk associated with technical change. Figure 1 summarises our model and the main components of our rationale.

Figure 1. The model



Inertia strategies appear to be a rational behaviour in which technological risk leads risk adverse organisations to aim for high levels of reliability through the reuse of validated technologies and it ends to a rational situation of technical inertia. One can notice that this model does not integrate the influence of the Net Present Value (NPV) of innovative investments to explain why organisations implement inertia strategies. We made this choice using the argument that is impossible to compute the NPV for radical innovations. Beyond a level of uncertainty it is useless to compute the NPV because the appropriation of innovation investments is unreliable. Because our model aims at understanding the influence of risk on innovation, we assume that it only suits for a high level of technological uncertainty in which situations of radical uncertainty cannot be ignored.

4 Empirical Framework: the Space Industry

In order to test our model, we selected an innovative industry that faces high levels of technological risk. We made our selection thanks to the literature on Complex Products and Systems (CoPS) and High Reliability Organisations (HRO). CoPS "can be defined as any high-cost, engineering-intensive product, subsystem, system, […], capital good or construct supplied by a unit of production" (Davies and Hobday, 2003, p. 21). CoPS includes aircraft carriers, air-traffic control systems, nuclear power plants, space launch vehicles, satellites, space stations (Hobday, 1998). HROs are a group of organisations that emerged to operate complex and hazardous technical systems (Rochlin, 1996; Demchak, 1996). HROs operate systems such as: aircraft carriers, air-traffic control systems, nuclear power plants, space launch vehicles (Roberts, 1990; Vaughan, 1990). In other words, we can say that HROs operate CoPS.

CoPS studies assume that CoPS industries are innovative, and studies on HROs assume that HROs face high levels of risk. Among the illustrations evoked in CoPS and HRO studies, we chose to focus on the space industry because we consider it to be very innovative and risky. As the space industry has different competing definitions, we need to mention that we retain the one provided by the OECD (2007, p.18). The space industry is manufacturing complex systems such as satellites, space probes, space stations, launchers and ground stations. We exclude from the space industry the non-space actors that broadcast content through satellites or manufacture small navigation equipment.

4.1 The Space Industry is Innovative

Based on R&D intensity, the aerospace industry is among the most innovative industries (Mazzucato and Tancioni, 2008). However, it is difficult to find figures only for the space industry. We can make an assessment by exploiting the fact that government budgets in the OECD countries reserved 36.4% to R&D of their expenditure on space activities in 2004 (OECD, 2007). As institutional clients represent between 40% and 70% of space industry revenue, we can approximate the weight of public funded R&D as representing roughly 14% to 24% of the industry revenue.

More generally, we can say that is a very innovative industry because it manufactures very small batches. Most space products are unique or are made in batches of less than 10, which suggests that space organisations tend to manufacture prototypes. Even in telecommunications satellites, where the level of standardisation is very high, each satellite is customised significantly according to the specific needs of the client. In the manufacture of space probes and scientific satellites, the difference between each product is so important that the idea of a dominant design tends to disappear.

The need to manufacture prototypes demonstrates that a large part of the activities of space organisations is related to experimental development (Potteck, 1999; OECD, 2002). These activities can be defined as a type of systematic R&D that draws on existing knowledge gained from research and practical experience, to produce new systems or improve already produced systems, in order to take advantage of the specific features of the space environment. Based on this argument we can say that most space industry activities are innovative.

4.2 Technological Risk in the Space Industry

The space industry faces important technological risk because the occurrence and the cost of technical breakdowns are high. This situation can be summarised by referring to a general rule in insurance theory which argues that the extent of disasters is a negative function of their occurrence. This applies to most human activities but not to space activities where failures simultaneously encompass significant cost and frequent occurrence (Ritchie et al., 1998, p. 836). As a consequence, between 1990 to 2004, claims were higher than premiums in space insurance activity 5 years.

We next present some indications regarding the sources and the levels of the technological risk in space activities by detailing the occurrence and cost of technical breakdowns.

4.2.1 Occurrence of Breakdowns: Level of Technological Uncertainty

As space organisations tend to manufacture innovative products, more specifically prototypes, the occurrence of technical breakdown is frequent (Rosenberg, 1982). The positive effects of learning from experience are hampered since space products do not always display a dominant design.

The hostile environments in which space products are exploited increase the possibilities of technical breakdowns. For instance, space products can be operated in the exploration of new planets and environments about which space organisations lack scientific knowledge about their features. Space products are also used in the environment of the Earth which can demonstrate unfriendly features, such as vibrations during the launch phase, and bad weather conditions that may damage launchers and/or ground stations.

The use of innovative products in hostile environments suggests that there is a high level of uncertainty in space activities. This is reflected in two statistics: first, between 1998 and 2009 we observed 1 space launch failure for every 15.17 launches (Computed from Kyle, 2010); second, among the 218 space probes launched since the beginnings of planetary exploration whose missions were accomplished prior to 2008, we can count only 122 successes (Computed from NASA, 2008).

4.2.2 The Costs of Breakdowns: Amounts of Losses

Technological risk is significant in space activities because the cost of a technical breakdown is generally very expensive for the space organisations involved. This is because space products are very expensive. For example, a telecommunication satellite and a launcher cost as much as an airliner. However, as Fischhoff et al. (1984) note, risks are systemic in nature which implies that the losses are seldom limited to the cost of the defective technical subsystem. This argument is relevant to an understanding of the cost of technical breakdowns in space.

Space activities display a notable specificity regarding the difficulties involved in fixing breakdowns. It is impossible to fix most of the breakdowns that occur after the liftoff phase because the interactions with launchers, satellites and space probes become very limited. It is impossible to fix the launcher during liftoff, and software updates are only possible when spacecrafts are operational. In other words, a breakdown in secondary equipment may jeopardise the entire space system (satellite plus launcher). The systemic nature of the cost of breakdowns becomes especially obvious if we recall that space products are capital goods used to provide telecommunication, weather forecasting and navigation services. Thus, if a telecommunication satellite breaks down because of a failure in secondary equipment, telecommunications services are rendered unavailable, which leads to additional losses.

The losses induced by a technical breakdown would be further multiplied if all the negative consequences of a breakdown are integrated; however, it is impossible to estimate these losses. In our view, therefore, we should focus only on those losses whose value can be fairly reliably estimated.

5 Test of the Model

In our model the level of technological risk leads to the implementation of inertia strategies. More precisely, we want to test the following hypothesis: the higher the level of technological uncertainty and the higher the cost of breakdowns in space products the more space organisations will adopt intensive inertia strategies.

The independent variables are the level of technological uncertainty (U) and the cost of breakdown (C); the dependant variable is the implementation of inertia strategies (I). We test this hypothesis using data from the quality and procurement departments of a major prime contractor in the European space industry, collected in 2006. Our database includes 573 types of technologies bought by the prime contractor from its suppliers, that is, for each type of technology we have three proxy variables U, C and I.

Type of technology refers to the set of products used in space activities, which display common features. Types of technologies include active discrete electronic components, batteries, connectors, electromechanical parts, engines, noise reduction filters, optoelectronics components, manufacturing tools, and cables.

5.1 Variables and Proxy Variables

We present first the independent variables, which are the cost of breakdown and the level of technological uncertainty, after we present the dependant variable which is the inertia strategies.

5.1.1 The Independent Variables

The cost of breakdown.

In order to measure the costs of a breakdown, we decided to focus on the cost of the defective technology because it is very difficult to estimate the negative consequences of a technical breakdown. We computed the average price of each of the 573 types of technologies bought by the prime contractor from its suppliers, using this as an estimation of the cost of breakdown (C). Table 1 presents the populations of technologies in the functions of their breakdown costs.

Table 1. Distribution of technologies and their breakdown costs

Cost of breakdown (C)	**Frequency**	**%**
[0.31992; 0.96006]	127	22.16
[0.96006; 1.60023]	153	26.70
[1.60023; 2.24040]	35	6.10
[2.24040; 2.88062]	258	45.02

The least expensive types of technology cost 0.31 million Euros while the most expensive type costs 2.88 million Euros with a mean of 1.78. We observe that 45.02% of the types of technologies are in the most expensive quartile, which implies that space activities require a large proportion of expensive technologies. The first and second quartiles contain comparable populations while the third quartile has the smallest population.

The level of technological uncertainty.

In order to measure the level of technological uncertainty, we employ the popular method proposed by several versions of the MIL-HDBK-217, a military handbook on reliability prediction. This method estimates a failure rate with a simple model composed of a base failure rate for 10^6 hours of use multiplied by a set of coefficients that specify the particular context. The base failure rate can be regarded as the occurrence of technical type failures, in normal conditions, where the coefficients include for instance the environment in which the technical element operates, and its intrinsic quality.

We decided not to estimate failure rates for the 573 technology types retained but rather to focus on the coefficients that influence these rates. This choice was based on the difficulty involved in computing individual failure rates, and also that the idea of failure rates in innovative activities is a difficult issue as innovation is related to unpredictable outcomes. Using the definition of contexts provided by Knight (1921), we place innovation in the context of "uncertainty" rather than in the "risk" one.

Among the coefficients that influence failure rates, the one describing the nature of the environment in which the technical elements operate is always included in models of reliability prediction. MIL-HDBK-217E (1986) considers 13 types of environments including ground benign, ground fixed, naval, space flight, and missile launch. The more hostile the environment, the higher the value of the coefficient. This means that, the MIL-HDK-217 reliability prediction manual postulates that the hostility of the environment has a positive influence on the occurrence of breakdowns.

We exploit this to identify the levels of technological uncertainty for the 573 types of technologies in our database. For each technology type, we can identify the environment in which it will be operated. We retained three different environments displaying increasing levels of technological uncertainty. These are ground benign (the least hostile environment, e.g. office spaces), ground fixed (intermediate hostile environment, e.g. outdoor), and missile launch and space flight (the most hostile environment faced by launchers and their payloads). For each type of environment, we arbitrarily attribute a coefficient that represents a level of technological uncertainty.

Table 2. Distribution of technologies in functions of the level of uncertainty

Type of environment	Level of technological uncertainty (U)	Number of technologies
Ground benign	1	253 (44.15%)
Ground fixed	2	92 (16.06%)
Missile launch and space flight	3	228 (39.79%)

We decided to attribute the coefficients 1, 2, and 3 to respectively the ground benign, ground fixed, and missile launch and space flight. We assume that missile launch and space flight induce the highest level of technological uncertainty because they are respectively more hostile than ground benign and ground fixed environments. We observe that majority of the technologies types bought by the prime contractor are used in the least hostile environment (ground benign : 44.15%) while the technologies that will used in the most hostile environment (missile launch and space flight) represent 39.79%.

5.1.2 The Dependant Variable

Theoretical foundations of proxies.

Figure 1 shows that the variable “inertia strategies” has two dimensions - “level of reliability required” and “reuse of validated technologies”. These dimensions are linked since the model considers that a high level of reliability induces reuse of the technologies. We decided to focus on the dimension “level of reliability required” in order to avoid the need for ad-hoc proxies for the other dimensions. Several scholars have argued that there is a positive link between the existence of situations of inertia and the implementation of reliability and quality constraints. For instance, Grenard (1996) and Hannan and Freeman (1984) indicate that quality and reliability are achieved through the codification of know-how and the processes that contribute to limiting change. In other words, we assume that the level of reliability required is a proxy for the inertia strategies.

More precisely, we estimate the level of reliability required by focusing on quality assurance. We base this choice on the study of Meeus and Oerlemans (2000) which uses quality assurance as a proxy for inertia in a study comparing the relevance of adaptation and selection perspectives in the evolutionary approach. Quality assurance imposes a set of constraints that lead several scholars to underline that it tends to slow down innovation dynamics (Savall and Zardet, 1996; Sauleau and Mathy, 1997).

Some argue that quality assurance is tool for risk management to prevent failures (Hassid, 2008). Since inertia strategies are viewed as a type of innovation strategies used to limit failures in innovation processes, we see this argument as reinforcing the relevance of quality assurance as a proxy.

In space activities, we can say that quality assurance refers to a program for systematic monitoring and evaluation of the technology types bought from suppliers. Ravix (2000) underlines that in 1994, 96.6% of aerospace organisations had been awarded quality assurance certification such as ISO. Quality assurance is a popular management tool implemented by almost all the organisations in the industry.

Measuring the dependant variable.

Because not all monitoring and evaluating behaviours are relevant to construct the proxy, we decided to focus only on the five most relevant behaviours implemented by the quality department of the prime contractor when purchasing technology types. The behaviours we selected are for instance: (1) the technology type t_i available in the database of purchasing department is included in the quality department's database. If it is, this means that t_i is a technology for where reliability is relevant; (2) the technology type t_i is included in the database of the supplier's quality department based on quality insurance norms such as ISO, RG Aero, or RAQ; (3) the technology type t_i available in the database of the quality department is evaluated after consumption or through an audit?

We can establish the degree to which each technology type is associated with specific number of monitoring and evaluating behaviours, on a scale from 0 to 5. A technology type scoring 5 is regarded as being a technology where the highest level of reliability is required and above all one where inertia strategies are the most intensive. The lowest score describes a situation where the inertia strategies are the less intensive.

Table 3 shows the population of technology types according to intensity of inertia strategies.

Table 3. Distribution of technologies in functions of the intensity of inertia strategies

Intensity of inertia strategies (I)	**Number of technologies**	**Percentage**
0	230	40.14%
1	62	10.82%
2	39	6.81%
3	23	4.01%
4	168	29.32%
5	51	8.90%

We observe that the most frequent inertia strategies used by the prime contractor are the least intensive since they apply to 40.14% of the technologies bought. The second most frequent inertia strategies display an intensity level at 4 and apply to 29.32% of technologies. It is interesting that the most intensive inertia strategies are related to only 8.90%, and second that the average intensity of inertia strategies is only 1.98. We would have expected a higher frequency for this level of intensity as well as a higher mean for an industry assumed to exhibit intensive inertia strategies.

5.2 The Formal Model

In this paper, we test the hypothesis that: *the higher the level of technological uncertainty and the higher the cost of breakdowns in space products the more space organisations will adopt intensive inertia strategies*. This hypothesis summarises our model which can be written formally as:

$$I_i = \hat{a}_1 U_i + \hat{a}_2 C_i + \hat{a}_0 \qquad (1)$$

I_i denotes the intensity of the inertia strategies for the technology type i; U_i represents the level of technological uncertainty for the technology type i; and C_i is the cost of breakdown of technology type i. There are 573 technologies types thus i=1,2,…, 573. We estimate the coefficients ($\hat{a}_0$, $\hat{a}_1$, $\hat{a}_2$) using Ordered Logit Regression (OLR) and Ordinary Least Square (OLS) methods.

We choose OLR because our dependant variable is qualitative, multinomial and ordered. However, since this does not comply with parallel regression assumptions we also use the OLS method to compare results.

5.3 Results

Our results tend to validate the hypothesis since we observe a positive relation between level of technological uncertainty and cost of breakdown on the one hand and intensity of the inertia strategies adopted by the prime contractor on the other. We present the results of the OLR and OLS regressions in Table 4.

Table 4. Results computed with OLR and OLS methods

Independent var.	**OLR**	**OLS**
	Coefficients	
Technological uncertainty (U)	1,769*	1.140*
	(14.79)	(19.33)
	5,870592	
Cost of breakdown (C)	1,348*	0.793*
	(13.50)	(15.58)
	3,850327	
Intercept		-1.666*
		(-11.64)
McKelvey & Zavoina's R^2	0.627	
R^2		0.569
Prob> chi2	0.0000	
Prob> F		0.0000
Observations	573	573

* Significant at 1% level
z-statistic and t-statistic and in parenthesis
Odds ratios in italics

The OLR coefficients should be interpreted as follows: an increase of 1 point in technological uncertainty increases the intensity of inertia strategies by 1.76 points, with the other variables in the model held constant. In order to simplify interpretation of the OLR coefficients, we compute the odds ratios (in italics in the table). We interpret the odds ratios as follows: an increase of 1 point in technological uncertainty induces 5.87 times more frequent the adoption of more intensive inertia strategies than the adoption of less inertia strategies, given the other variables are held constant.

The results of both regressions are quite similar. The coefficients are positive and statistically significant which tends to validate the hypothesis proposed in this paper. Also, in both regressions, R^2 is around 0.6 which indicates goodness of fit with our econometric model. We observe also that in both regressions the coefficients related to technological uncertainty are more important than those related to the cost of failure. Level of technological uncertainty has more influence on the intensity of the inertia strategies adopted by the prime contractor. This observation is confirmed by the partial correlation coefficients presented below.

Table 5. Partial correlation coefficients

	I	*U*	*C*
I	*1*		
U	*0.6218**	*1*	
C	*0.5366**	*0.1868**	*1*

** Denotes significance at the 1% level*

The correlation between inertia strategies and technological uncertainty is 0.62, whereas the correlation between inertia strategies and cost of breakdown is lower at 0.53. Based on Table 5, we also observe that the correlation between technological uncertainty and cost of breakdown is low.

6 Discussion

The aim of this paper was to study whether the issue of risk has an influence on innovation. Using a theoretical framework based on risk and innovation studies we proposed a model, summarised by the following hypothesis: the higher the level of technological uncertainty and the higher the cost of breakdowns in space products the more space organisations will adopt intensive inertia strategies. We used the space industry as a case to test this hypothesis. Results indicate that the issue of risk has an influence on innovation activities through the promotion of inertia strategies.

These strategies are a type of innovation strategies that integrate the technological risks associated with innovation. Inertia strategies are relevant in contexts where situations of radical uncertainty cannot be ignored and are employed in the design and manufacture of new products. As the space industry is dominated by experimental development activities, we may add that inertia strategies are relevant for this category of R&D activities.

Inertia strategies have led space organisations to codify processes for the purchase of technologies to prevent deviant behaviours that might reduce reliability. There are several aspects to this codification, such as extensive use of monitoring and evaluating behaviours when the technologies purchased are used in risky environments. Inertia strategies also draw on the principle of risk avoidance since our model argues that when risk is high, organisations tend to avoid new technologies and prefer to reuse tried and tested ones.

The introduction of this new type of innovation strategies helps to clarify the nature of R&D and innovation activities. Indeed, among the activities implemented in R&D and innovation, those related to experimental development are vague. As indicated in the Frascati manual (OECD, 2002) “it is difficult to define precisely the cut-off point between experimental development and pre-production development”. Experimental development activities are regarded as innovative since they are included in R&D activities; however, pre-production development activities cut across both the innovation and production areas. Because of the difficulty to define precisely the cut-off point, we cannot always know whether the activities related to experimental development are innovative or not. This unclear situation makes it difficult to define precisely the boundaries of innovative activities.

Thanks to the inertia strategies we provide a new concept which can help to face this problem. These strategies favour the industrial production of innovative products sufficiently reliable to be marketed. In other words, inertia strategies structure the experimental development and pre-production development activities, such as the prototyping, technical demonstrations, feasibility studies, project definition and trial production batch, in which the level of novelty is sometimes difficult to identify.

Because of the difficulty to define precisely the boundaries of innovative activities, organisations involved in a large proportion of experimental development activities, such as CoPS, may wonder whether they are being sufficiently innovative to ensure their future survival. Since on the one hand inertia strategies shape experimental development activities and on the other hand they lead to technical inertia, it could be diagnosed that the innovation activities are not sufficient. As a result, organisations may try to promote innovation, which choice results in reduced reliability of the innovative products and endangers firm survival because the technological risk is high.

Our model indicates that organisations engaging in significant experimental development activities in a risky context cannot diagnose situations of technical inertia that are dangerous for survival. Because inertia strategies are a rational behaviour in which the technological risk leads risk adverse organisations to aim for high levels of reliability by favouring the reuse of validated technologies, we cannot consider all situations of technical inertia as being dangerous. Inertia strategies lead to a reinterpretation of situations of technical inertia which cannot be systematically regarded as dangerous for firm survival. A slow innovation dynamics ensures high levels of reliability whereas an innovation race may lead to major failures which endanger survival.

We can use the example proposed by Rosenberg (1982) to illustrate the relevance of inertia situations. In the 1950s, de Havilland was the first aircraft manufacturer to market a jet engine airliner. As the de Havilland Comet 1 had no competition for four years, we can say that Boeing and Douglas displayed significant technical inertia. Rather than seeing this technical inertia as negative, Rosenberg argues that it was positive because Comet 1 suffered dramatic reliability problems caused by the use of jet engines. At that time there was important technological uncertainty regarding the influence of jet engines on metal fatigue, which led to numerous accidents and incidents.

Our model shows that no specific catch up efforts have to be decided on when a technological delay is identified in a risky context. The organisation needs to pursue its innovative efforts based on inertia strategies because it is better to learn from the failures of competitors than from one's own failures.

7 References

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