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Are Incremental Innovations A Suboptimal Outcome? The Role of Uncertainty and Loss Aversion

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Abstract **Review Article**

Incremental innovations appears to be much more frequent than radical innovations. Possible explanations rely on the effect of the degree of competition in the market. The paper, on the contrary, focuses on agents' attitude towards status quo and con- servativeness and specifies the conditions where the preference for incremental innovations represents an optimum. In fact, the welfare generated by radical innovations drops dramatically when agents are uncertainty-averse and/or loss-averse.

Keywords: Incremental innovation, Radical innovation, Uncertainty, Loss aversion.

JEL Classification: D60, D81, O32.

1. INTRODUCTION

Radical breakthroughs have been usually judged as a crucial device to foster economic growth. However, the vast majority of innovations deals with simple improvements of the existing technology. The technology behind modern aircrafts or automobiles, cameras etc. has been built through continuous small ameliorations: probably this way of proceeding requires longer time, but we cannot forget that these small paces are still sources of welfare.

Recent empirical evidence about firms' innovativeness shows that established firms appear extremely conservative when deciding the innovative strategy to adopt. A common classification distinguishes strategies according to how radical they are compared to current technology (Freeman and Soete, 1997). Data prove that cumulative and incremental improvements are preferred to breakthrough inventions in the 95% of enterprises that engage in innovation.

Instead of pursuing revolutionary changes in products or processes, firms seem to look for ”greater user-friendliness, increased reliability, marginal additions to applications, expansion of capacity, flexibility in design” (Baumol, 2004), that are usually pre-announced and pre-advertised.

This paper focuses on the role of uncertainty and loss aversion in presence of the sunk costs related to a radical breakthrough. Potential innovators introducing radical innovations are exposed to Knightian uncertainty and to losses as opposed to risk (embodied in incremental innovations) where there is a unique distribution that summarizes the stochastic environment. The main contribution of the work consists of investigating the welfare cost of uncertainty and losses in a New- Schumpeterian model of growth. The results show that, when information is vague, opportunities are abundant and agents are loss-averse, incremental innovations might turn out to be an optimal outcome if compared to radical innovations that bring about Knightian-uncertain outcomes and might imply losses.

2. Radical vs. incremental innovations

The difference between radical and incremental innovations can be eas ily figured out at least at an intuitive level. However, both economics and business studies have not produced a unique characterization of innovative strategies according to their degree of innovativeness (Garcia and Calantone, 2002). The labels ‘radical' and ‘incremental' belong to managerial literature, that does not offer a unique description of the difference between the two concepts. In fact, there are many dimensions along which authors calibrate the degree of innovativeness (Battaggion and

Grieco, 2009): the level of risk implied in the strategy (e.g. Kaluzny, Veney and Gentry, 1972; Duchesneau, Cohn and Dutton, 1979; Hage, 1980; Cardinal, 2001), obviously greater in the case of radical breakthroughs; the type of processed knowledge (e.g. Dewar and Dutton, 1986; Henderson, 1993), that might involve a completely new developments or simply enlarge the existing base; performance improvement and cost reduction (e.g. Nord and Tucker, 1987), that reflect the higher investment needed to move onto a new trajectory; the eventual opening of a new market and consequent applications (e.g. O'Connor, 1998; Henderson and Clark, 1990), that might derive from a revolutionary contribute.

Furthermore, if we involve the concept of ‘technological trajectory', an innovative strategy can be interpreted as a choice between specific paths of technological change. Technological change occurs within paradigms (Kuhn, 1970) and is associated with changes in the paradigms themselves.

Dosi (1988) defines a ‘technological paradigm' as a pattern of solutions to selected techno-economic problems, based on particular principles derived from natural sciences, and on specific rules aimed at acquiring new knowledge. Similar concepts are the dominant design of Abernathy and Clark (1985) and the optimal recipe (Bjorn-Anderson, EarI, Holst and Mumford, 1982). The technology evolves along a techno- logical trajectory, identified with ”the activity of technological progress along the economic and technological trade-offs defined by a paradigm” (Dosi, 1988). In this perspective, incremental innovations aim at giving better answers to questions shaped by the existing paradigm, whereas radical innovations represent a shift onto alternative trajectories and respond to different needs.

Finally, the level of firm's innovativeness can be affected by external environment conditions. Technological change may lead to huge turbulence and dramatic discontinuities such that previously developed competences become obsolete (‘competence-destroying' technological change); when consistent modifications in the existing knowledge, competences and routines are not required and slight adaptations are enough, technological change is defined ‘competence-enhancing' (Anderson and Tushman, 1990).

Although diffused in managerial studies, the terms ‘radical' and ‘incremental' are not used explicitly in the economic literature. Nonetheless, similar concepts are analyzed in the context of process innovations. Industrial organization works describe as ‘drastic innovations' those changes in technology that determine a decrease in costs such that the new equilibrium price lies below the pre-innovation cost and consequently turn the innovator into a monopolist. On the other hand, ‘non drastic' or ‘gradual' innovations still affect costs, but only introducing an asymmetry that does not transform the market into a monopolistic one. Recalling previous consideration in managerial literature, drastic innovations can be interpreted as a particular manifestation of radical innovations that affect costs and market structure in a dramatic way.

Summing up, whatever the characterization of radical and incremental innovations we can find in managerial and economic literature, we emphasize the fact that choosing a strategy's degree of innovativeness has heavy implications in terms of the innovator's performance. There- fore, it will be fruitful to analyze the mechanisms behind this decision, and to understand the reasons of this preference in favour of the inertial behavior displayed by data.

2.1. Uncertainty and loss aversion as explanations for inertia

When an innovative strategy is evaluated in comparison to another, two strong forces move in opposite directions: inertia (related to status quo bias and path dependence), driving the potential innovator toward a choice that is the closest to the current technology, and preemption, that stimulates the potential innovator to establish the highest performance gap with his competitors. In this paper, we focus on the individual decision process that leads to the choice of an innovative strategy without accounting for strategic interaction among potential innovators (see below).

The preference for incremental innovative schemes emerging from the empirical evidence may be interpreted as one of the widespread con- sequences of individual attitude towards the status quo. Due to loss aversion, cost of thinking, psychological commitment to prior choices, transaction costs (Samuelson and Zeckhauser, 1988), an option may be- come significantly more popular when it is designated or perceived as the ‘status quo' (Kahneman, Knetsch and Thaler, 2000). Several studies on consumer's behavior illustrate that people attach undue importance to their current commodity bundle, revealing an "apparently irrational reluctance" to switch to alternative ones (Hartman, Doane and Woo, 1991). Furthermore, managerial enquiries testify that inertia, compart mentalized thinking and ambiguity constitute learning barriers to the development of drastically new paths: firms tend to proceed as they always did, preserving the status quo rather than capitalizing market information (Adams, Day and Dougherty, 1998). This outcome, on one hand, derives from the difficulties arising when an organization needs to change established routines and reframe the problem situation. On the other hand, lock-in to sub-optimal technologies (e.g. Farell and Soloner, 1985; Arthur, Ermoliev and Kaniovsky, 1987; Witt, 1997) may be due the emergence of network externalities and increasing returns to adop tion for consumers (Katz and Shapiro, 1985; Choi, 1994).

In this line of reasoning, the choice of the degree of innovativeness is not only a consequence of evaluations on performance and costs. On the contrary, a crucial role in determining the decision between follow ing revolutionary or established trajectories is played by cognitive and idiosyncratic attitudes such as uncertainty aversion and loss aversion. This insight is consistent with the fact that radical innovation generally seems not to take place in established firms but to be conveyed by new competitors'.

The issue we address here is whether this attitude towards inertia is a distortion that drives firms away from the optimality condition (the psychological studies above speak of ‘biases' that force agents not to reach optimality) or if it is somehow the direct consequence of a maximizing choice for agents whose preferences reflect uncertainty and/or loss aversion.

Among the possible explanations that also find a rational validation for inertial behavior we can find two additional (and related) strands of literature: convex adjustment costs and technical information. The literature in investment demand usually refers to convex adjustment costs (Hamermesh and Pfan, 1996). If firms exhibit convex adjustment costs of the innovative investment, their optimal choice should consist of sustaining small incremental investments instead of devoting once for all a larger amount to finance a radical innovation. When uncertainty is large, it could be optimal to ”buy more protection in the form of less initial investment” (Caballero, 1991). On the other hand, an alternative explanation suggests that revolutionary changes in complex products may require more demanding technical information and techniques than is needed for simply extending the original idea, and firms might be not endowed with it.

2.2 Preemption

The existence of a performance gap has conventionally been indicated in the literature as a stimulus to enhance innovative activity (Ellie, 1983): this stimulus can result from a change in the output standard or from a decline in performance on past standards (Hage, 1980), or can represent a mean available to overcome competitors when exploiting strategies are exhausted. The notion of ‘gap' automatically refers to a comparative setting and is linked to the traditional concept of ‘preemption incen- tive'(Gilbert and Newbery, 1982; Salant, 1984): when facing actual or potential competition, the challenge of risk might be accepted in order to prevent rivals' success. As emphasized above, Arrow (1962) demonstrates that the innovation value for a monopolist is negligible because innovation could only affect profits (‘replacing them with higher prof- its) without modifying the current market structure. The threat of a potential entrant, on the contrary, might stimulate innovation: entry often encourages the incumbents to seek out new profit opportunities instead of protecting existing rents. In fact, data prove that small, new entrants work like a vehicle for introducing radical innovations and that high entry rates are usually associated with high rates of innovation and increase in efficiency (Geroski, 1995).

Although there is a vast literature on the debate about the relationship between intensity of competition, market structure and profitability of innovation, no agreed-upon framework has been individuated yet, and the performance gap is not universally considered enough to motivate innovation Scholars speak of ‘Schumpeterian trade-off' be- tween a ‘strategic' incentive to innovation that rises from competition, and a ‘pure' incentive that derives from innovation returns (and can be completely exploited only under specific appropriability regimes). Sub- sequent analyses of the Schumpeterian trade-off across oligopolistic in-dustries, however, provided mixed results: for instance, the incentive to introduce a cost-reducing innovation is greater for a Bertrand com-petitor than for a Cournot competitor (Delbono and Deniccolò, 1990). If products are horizontally differentiated, the degree of differentiation favours one form of competition or the other (Bester and Petrakis, 1993). Bonanno and Haworth (1998), on the contrary, show that vertical differentiation always implies a higher increase in profits associated with a cost reduction innovation in the case of Cournot competition. Endogenous growth literature investigates the issue as an implication of the relationship between competition and growth (see next section).

In synthesis, the need of establishing a performance gap promotes innovation only under specific and non agreed-upon conditions. Our model does not focus on these aspects.

3. The model

The model grounds on Romer (1994)'s and Aizenman (1997)'s Neo-Schumpeterian models of growth. These models explicitly allow for the introduction into an economy of new or improved types of goods. Early contributions to this branch of growth theory include Aghion and Howitt (1990), Grossman and Helpman (1991), Romer (1987, 1990), and Segerstrom, Anat, and Dinopoulos, (1990). These models of endogenous growth theory differs from the models in Lucas (1988) and Romer (1986), which emphasize external increasing retums, and from models in Jones and Manuelli (1990) and Rebelo (1991), which ground on perfect com- petition and assume that capital can be accumulated forever without driving its marginal product to zero. Both the external effects and per- fect competition models of endogenous growth assume that new goods do not matter at the aggregate level. The modeling innovation in the neo-Schumpeterian models of growth is that they take explicit account of the fixed costs that limit the set of goods and show that these fixed costs matter in a dynamic analysis conducted at the level of the econ- omy as a whole. This contrasts with the standard approach in general equilibrium analysis, in which fixed costs are assumed to be of negligible importance in markets. Nonetheless, as emphasized above there is an extensive literature on the topic in industrial organization: new growth models also depart from this literature because they do not capture the strategic interactions that emerge when there are only a small number of firms in a market.

The crucial premise in the neo-Schumpeterian models is that every economy faces virtually unlimited possibilities for the introduction of new goods, where the term "good" is used here in the broadest possible sense: it might represent an entirely new type of physical good, or a quality improvement; it might be used as a consumption good, or as an input in production. Here, the introduction of a new good represents an innovation.

In the way of capturing agents' attitude towards risk and uncertainty, the model follows the Schmeidler-Gilboa approach, that is based on the assumption that agents are both risk and uncertainty (in the sense of Knightian uncertainty) averse. If the innovator is a risk-neutral Bayesian agent, she would assign a uniform distribution to the returns of innovation. The expression $\frac{H+L}{2}$ represents the expected returns of the investment in innovation, where the probability assigned to both the successful and unsuccessful outcome is $\frac{1}{2}$ and is independent to the degree of vagueness about the outcomes of innovation.

However, according to Ellsberg (1961), agents behave differently than in this Bayesian description in two aspects: (1) they are unable to summarize the uncertainty in the form of a unique prior distribution, and (2) attach an extra-cost to invest in radical innovation that might be interpreted as an "uncertainty premium". In the Schmeidler-Gilboa approach, Knightian uncertainty induces uncertainty-averse innovators to discount by using a "hurdle rate" that is higher than the risk-free interest rate.

We consider an innovating agent who produces a final good Z by using labour (5) and N capital goods:

$Z = L^{1-\alpha} \sum_{i=1}^{N} x_i$ ……………. (1)

Where xi represent the N capital goods (intermediate inputs) and $0 \leq \alpha \leq 1$.

The new capital good n can be introduced either as a small improvement on the existing technology (incremental innovation) or as a disruptive opening up of a new technology (radical innovation).

3.1 Incremental innovation

The introduction of a new capital good n with an incremental innovation has the same marginal cost of all the capital goods and is equal to w. Standard cost minimization implies that their demand for capital good i is:

$x_i^d = \left(\frac{\alpha}{p_i}\right)^{1-\alpha} L$ ……………. (2)

Each producer faces a demand whose elasticity is $\frac{1}{1-\alpha}$.

A representative producer follows a markup rule, charging $p_i = \frac{w}{\alpha}$ for its input. Adding capital good n at the cost w will lead to profits equal to $\Pi_n = \frac{w^{-\alpha\prime}}{1+r} kL - wn$.

3.2 Radical innovation with uncertainty aversion

The introduction of a new capital good n with a radical innovation re- quires an "up-front capacity investment" which is firm-specific, whereas (as seen above) the marginal cost of all the current capital goods is equal to w.

Adding capital good n requires a sunk cost specific to that good. For simplicity, we assume that the dependence of the sunk cost on n is linear. Suppose, for example, that the cost of installing a capital good n is χn, where χ is a random shock that describes the degree of uncertainty of the innovation and the cost of implementing that kind of investment in a new technology.

There are two periods, denoted by t = 0, 1. Technology is established in period 0, and production takes place in period 1. The innovating producer chooses its R&D investment at the beginning of period 0, prior to the realization of χ. Establishing the capacity in period 0, the innovator uses in period 1 the capital good at a cost of w. In the absence of uncertainty, the innovator evaluates projects by applying a risk-free interest rate, denoted by r. A representative producer follows the same markup rule specified above.

Adding capital good n will lead to profits of

$\Pi_n(\chi) = \frac{w^{-\alpha\prime}}{1+r} kL - \chi n$ …………… (3)

Where

$$k = \frac{1}{1-\alpha} \alpha^{\frac{2}{1-\alpha}}$$

Profits are random, as there is uncertainty concerning the value of χ. For simplicity, we normalize χ to be either low ($\chi = 1 - \delta$) or high ($\chi = 1 + \delta$), $\delta > 0$, but assume that the precise probability of each state is unknown where 6 represents the range of possible outcomes.

A producer investing in a radical innovation is exposed to Knightian uncertainty. A useful decision rule in these circumstances is to maximize a utility index that provides a proper weight for the exposure to uncer tainty. A possible procedure is to construct two statistics. The first is the "worst scenario" wealth, denoted by N. The second is the "expected wealth" if one attaches a uniform prior to the distribution of the profits, denoted by $Eu(N)$. The shortcoming of $Eu(N)$ is that it does not put any weight to the uncertainty regarding the outcome of innovation. To correct this shortcoming, one can use a decision rule that maximizes a weighted average of the above two statistics:

$U = cN + (1 - c)Eu(N)$ ……………… (4)

Where 0 < c < 1 represents the degree of uncertainty aversion, i.e. the sub-jective probability that an agent attaches to the two possible scenarios. According to Gilboa and Schmeidler (1989)'s specification, $c = 1 - 2p$ (where p stands for the probability of an event) and captures the "vague- ness" of the information set. When p goes to zero, the information is precise and there is full confidence about the probabilities assigned. In other words, the innovator is risk neutral and attributes a uniform prior to the two events.

A larger p indicates less confidence about the as- signed probabilities and greater uncertainty aversion embodied in the non-additive probabilities, reflecting the ambiguity of the information.

If all firms share the same uncertainty aversion index c, the number of capital goods (N) is determined by:

$\bar{N} = \frac{w^{-\alpha'}}{1+\bar{r}} kL$ ………….. (5)

Where, $\bar{r} = (1 + r)(1 + c\delta) - 1 \approx r + c\delta$.

In the absence of uncertainty, the number of capital goods is:

$N = \frac{w^{-\alpha'}}{1+r} kL$ ………………. (6)

Uncertainty reduces the number of new activities. Labor captures part of the rents associated with capital deepening, hence the drop in investment impacts wages directly. The drop in welfare is proportional to the uncertainty embodied in the investment, being determined by the vagueness of the information (measured by s) and by the range of possible outcomes (measured by δ). To gain further insight regarding the relevance of uncertainty aversion, it is useful to contrast the behavior described above to the conduct of a conventional risk-averse Bayesian firm confronting the same situation. If all firm are alike, risk aversion alone induces second-order losses (i.e. losses proportional to δ^2) that are proportional to the degree of risk aversion. Risk aversion is important, but uncertainty aversion may play a dominant role in explaining the reluctance to invest in new technologies. In fact, if agents are both risk and uncertainty averse, both aversions may interact, potentially magnifying the welfare costs of uncertainty and of radical innovation. Knightian uncertainty associated to radical innovations inhibits the formation of new activities, leading to first-order losses, whereas risk aversion alone leads to second-order losses.

4. DISCUSSION AND CONCLUSIONS

Being aware of the determinants that shape the decision between incremental and radical innovations helps in delineating practices to stimulate specific types of innovative projects. Everybody says that radical innova tion is important (e.g. Leifer, O'Connor and Rice, 2001): consensus has emerged that conventional incremental improvements and cost reduction strategies are insufficient for getting a competitive advantage (Sorescu, Chandy and Prabhu, 2003) as direct consequence of worldwide diffusion of knowledge and industrial capability. Therefore, understanding radical innovation might eventually make their course shorter, less sporadic, less expensive, and less uncertain.

Nonetheless, from a welfare point of view, radical innovations might be inferior to incremental innovation. This paper is grounded on the idea that, between innovations that incorporate a breakthrough technology or innovations that provide a substantial increase in customer benefits, it is not obvious which are more valuable. Even if less spectacular and less dramatic, routine innovative activities can still accomplish a great deal: summing their achievements, large corporations' results have been very substantial. A very clear example is the airplane: the sophistication, speed and reliability of today's aviation equipment is probably attribut-able to the combined incremental additions made by routine research activities. Other observations testify that incremental and routinized innovative strategies have been responsible for a very spectacular share of the contribution of innovation to economic growth. According to Lundvall (1992), the cumulative impact of incremental innovations is just as great (if not greater), and to ignore this leads to a biased view of long run economic and social change.

This paper explains such a reluctance to invest in radical innovation by showing that, if agents are both uncertainty and loss averse, both aversions may interact, potentially magnifying the welfare costs of un-certainty and losses related to a radical innovation. Therefore, a decision in favour of a cumulative development of the existing technology, as in case of incremental innovation, is far to be suboptimal.

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