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Abstract

Technological refinements appears to be much more frequent than breakthrough innovations. We argue that this could be the result of an optimizing choice when the innovation revenues are exposed to Knightian uncertainty and innovators are loss-averse. The innovator's choice between breakthrough and incremental innovations is analyzed in the context of a neo-Schumpeterian growth model that accounts for the introduction of new goods and related sunk costs. The results show that the welfare generated by breakthrough innovations drops dramatically when agents are uncertainty-averse and/or loss-averse, but rises as innovators' experience increases.

1. Introduction

Breakthrough inventions 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. This conservative attitude affects either inventors or R&D labs (and then firms). The empirical evidence shows that experienced inventors produce a larger number of inventions, but each one of them is less likely to be a breakthrough due to the myopic exploitation of a well established technological path (Conti, Gambardella and Mariani, 2010). Furthermore, established firms appear extremely cautious when deciding the innovative strategy to adopt. Data prove that cumulative and incremental

improvements are preferred to breakthrough inventions in the 95% of enterprises that engage in innovation[1]. 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. For example, the technology behind modern aircrafts or automobiles, cameras etc. has been built through continuous small ameliorations: probably such a way of proceeding requires longer time, but these small paces are still sources of welfare.

This paper presents a theoretical welfare analysis of breakthrough and incremental innovations. The main contribution of the work consists of investigating the welfare cost of uncertainty and losses involved in a path-breaking innovation within the setup of a New-Schumpeterian model of growth. The choice of this theoretical framework is due to the particular suitability of this branch of models in capturing the joint role of new goods, fixed costs, and market power. The paper provides a theoretical basis to understand the motivations behind empirical results on established firms' and inventors' myopia and enriches the theoretical predictions with respect of the existing models of uncertain profitability of a breakthrough technology adoption (e.g. Doraszelski, 2004). Furthermore, the effects of innovators' experience on breakthrough innovations are studied. The results show that, when information is vague, opportunities are abundant and agents are loss-averse, path-breaking innovations that bring about Knightian-uncertain outcomes and might imply losses can result in a drop of welfare. Nonetheless, expert innovators are able to reduce information vagueness and limit such a loss.

2. Related literature

2.1 Breakthrough innovation vs. incremental innovations

The difference between breakthrough and incremental innovations can be easily 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 the managerial literature, that does not offer a unique description of the difference between the two concepts. In fact, there are many

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[1]A common classification distinguishes strategies according to how radical they are compared to current technology (Freeman and Soete, 1997).

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 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, Earl, Holst and Mumford, 1982). The technology evolves along a technological 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.

2.2 Uncertainty, loss aversion and experience

When an innovative strategy is evaluated in comparison to another, two forces move in opposite directions: inertia, driving the potential innovator toward a choice that is the closest to the current technology, and creativity, that stimulates the potential innovator to open a new trajectory.

The preference for incremental innovative schemes in the empirical evidence may be interpreted as one of the widespread consequences 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 become 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

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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, compartmentalized 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; Banerjee and Campbell, 2009) may be due the emergence of network externalities and increasing returns to adoption for consumers (Katz and Shapiro, 1985; Choi, 1994). Nonetheless, innovators with accumulated experience have been shown to be more efficient in searching and combining knowledge components (Fleming, 2001).

In this perspective, the choice of investing in a breakthrough innovation is not only a consequence of evaluations on performance and costs. A crucial role in determining the decision between following revolutionary or established trajectories is played by cognitive attitudes such as uncertainty aversion and loss aversion. This insight is consistent with the fact that breakthrough 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 myopic attitude towards inertia is a distortion that drives innovators away from the optimality condition (the psychological studies above speak of "biases" that force agents not to reach optimality) or if it is the consequence of a maximizing choice for agents whose preferences reflect uncertainty and/or loss aversion[2].

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[2]Among the possible explanations that also present 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.

2.3 Competition among innovators

The existence of a performance gap has conventionally been indicated in the literature as a stimulus to enhance innovative activity (Ellie, 1983). The notion of gap is related to the traditional concept of "preemption incentive" (Gilbert and Newbery, 1982; Salant, 1984): when facing actual or potential competition, the risk challenge might be accepted in order to prevent rivals' success. In his seminal work, Arrow (1962) demonstrates that the innovation value for a monopolist is negligible because innovation could only affect profits without modifying the current market structure. The threat of a potential entrant, on the contrary, stimulates innovation: entry encourages the incumbents to seek out new profit opportunities instead of protecting existing rents. 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" between 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). Further analysis of the Schumpeterian trade-off across oligopolistic industries, however, provided mixed results.[3] In synthesis, the need of establishing a performance gap promotes innovation only under specific and non agreed-upon conditions.

In the Neo-Schumpeterian models as the one presented below, competition can work on two channels: competition on the goods market takes the form of either a higher degree of substitution between similar goods or of a greater number of competitors (Klump, 1998).

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[3]For instance, the incentive to introduce a cost-reducing innovation is greater for a Bertrand competitor than for a Cournot competitor (Delbono and Denicolò, 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.

3. The model

The model grounds on Romer (1994)'s and Aizenman (1997)'s Neo-Schumpeterian models of growth in their closed-economy version, enriched by Schmeidler-Gilboa's assumptions on agents' uncertainty aversion. The Neo-Schumpeterian models explicitly allow for the introduction into an economy of new or improved types of goods [4]; their peculiarity consists of taking explicit account of the fixed costs that limit the set of goods and of showing that these fixed costs matter in a dynamic analysis conducted at the level of the economy 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. Furthermore, new growth models also depart from the literature in industrial organization because they do not capture explicitly 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 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 capital good represents an innovation.

The firm lives two periods: in period 0, it decides the type of innovation to invest in, and (if it is the case) sustains the sunk costs needed for a breakthrough innovation; in period 2, production takes place. We consider an innovating firm who produces a final good Z by using labour (L) and N capital goods x_i according to the following production function:

$$Z = (L)^{1-\alpha} \sum_{i=1}^{N} (x_i)^{\alpha}; 0 < \alpha < 1$$

(1)

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[4]These models of endogenous growth theory differs from the models in Lucas (1988) and Romer (1986), which emphasize external increasing returns, and from models in Jones and Manuelli (1990) and Rebelo (1991), which ground on perfect competition and assume that capital can be accumulated forever without driving its marginal product to zero. Both the external effects and perfect competition models of endogenous growth assume that new goods do not matter at the aggregate level.

The production of capital good x_n takes place using the services of labour according to the function $x_n = L_n$ where L_n stands for the labour in activity n, whereas L is the labour employed in the production of the final good. For simplicity, as standard in this literature, w is the real wage and represents the marginal cost of producing both the capital goods and the final good.

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 (breakthrough innovation). Standard cost minimization implies that the demand for capital good i is:

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

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

3.1 Breakthrough innovations with uncertainty-averse agents

In the way of capturing agents' attitude towards risk and uncertainty, this 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 (Gilboa and Schmeidler, 1989). If the innovator is a risk-neutral Bayesian agent, she would assign a uniform distribution to the returns of innovation. The only information available is that the project return is bounded between L and H, where $L < H$. The expression $\frac{H+L}{2}$ represents the expected return of the investment in innovation, where the probability assigned to both the successful and unsuccessful outcome (H and L respectively) is $\frac{1}{2}$ and is independent to the degree of vagueness about the outcomes of innovation: a risk-neutral Bayesian agent will refer to this expression as the expected return. However, as emphasized by 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 a breakthrough innovation that might be interpreted as an "uncertainty premium". In the Schmeidler-

Gilboa approach, Knightian uncertainty induces uncertainty-averse innovators to prefer more transparent information and therefore to discount by using a "hurdle rate" that is higher than the risk-free interest rate. The introduction of a new capital good n by means of a path-breaking innovation requires an "up-front capacity investment" which is specific to the new capital good, whereas the marginal cost of all the current capital goods is equal to w.

There are two periods, denoted by $t = 0,1$. Adding capital good n requires a sunk cost specific to that good; the innovator commits its investment at the beginning of period 0, whereas production takes place in period 1. For simplicity, we assume that the dependence of the sunk cost on n is linear and is normalized at 1 (we assume it is known). On the contrary, future revenues are uncertain due to the fact that the new technological trajectory can be successful or not (and this is not known *a priori)*. We label χ the random shock that describes the degree of uncertainty of the innovation that affects future revenues. Technology is established in period 0, and production takes place in period 1. At the beginning of period 0, prior to the realization of χ, the innovating firm chooses its R&D investment. For simplicity, we normalize χ to be either low ($\chi = 1 - \delta$) or high ($\chi = 1 + \delta$), $\delta \geq 0$, but assume that the precise probability of each state is unknown and δ represents the range of possible outcomes of the random variable χ. Ameliorations of the existing technology are assumed to involve no uncertainty on the profitability of the technology (as it is the current one): $\chi = 1$ (and $\delta = 0$) captures the case of incremental innovation, where, in the absence of uncertainty, the innovator evaluates projects by applying a risk-free interest rate, denoted by r.

A representative producer of the x_i capital good follows a mark-up rule, charging $p_i = \frac{w}{\alpha}$ for its input. Adding capital good n will lead to profits equal to

$$\Pi_n(\chi) = \frac{\chi(p_i - w)x_i}{1 + r} - n = \frac{\chi(w)^{-\frac{\alpha}{1-\alpha}}}{1 + r} \frac{1 - \alpha}{\alpha} \alpha^{\frac{2}{1-\alpha}} L - n = \frac{\chi(w)^{-\alpha'} kL}{1 + r} - n$$

(3)

where $k = \frac{1-\alpha}{\alpha} \alpha^{\frac{2}{1-\alpha}}$ and $\alpha' = \frac{\alpha}{1-\alpha}$.

Investing in a breakthrough innovation exposes the innovator 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 uncertainty. The procedure we follow consists of constructing two statistics. The first is the "worst scenario" wealth, denoted by $\underline{\Pi}$. The second is the "expected wealth" if one attaches a uniform prior to the distribution of the profits, denoted by $E_u(\Pi)$. The shortcoming of $E_u(\Pi)$ is that it does not put any weight to the uncertainty regarding the outcome of the innovation. To correct this shortcoming, we use a decision rule that maximizes the innovator's utility U as a weighted average of the above two statistics:

$$U = c\underline{\Pi} + (1 - c)E_u(\Pi); \ 0 < c < 1$$

$$(4)$$

where c represents the degree of uncertainty aversion embodied in the decision to invest, with $0 \leq c \leq 1$. When c goes to zero, we have the case of a risk-neutral Bayesian agent who attributes a uniform prior to the two events. A larger c indicates less confidence about the assigned probabilities and greater uncertainty aversion.

Proposition 1. *An uncertainty-averse agent will invest in a breakthrough innovation if* $W > n(1 + \bar{r})$.

Proof. In the absence of any investment in innovation, firm's profit are Π_0 . The investment in a breakthrough innovation will be undertaken if it increases the expected utility:

$$c\left[\Pi_0 + \frac{(1 - \delta)(w)^{-\alpha'}kL}{1 + r} - n \right] + (1 - c)\left[\Pi_0 + \frac{(w)^{-\alpha'}kL}{1 + r} - n \right] > c\Pi_0 + (1 - c)\Pi_0$$

that leads to $(w)^{-\alpha'}kL > n\dfrac{1 + r}{1 - c\delta}$. If we label $W = (w)^{-\alpha'}kL$, $\bar{r} = \dfrac{r + c\delta}{1 - c\delta}$ and $1 + \bar{r} = \dfrac{1 + r}{1 - c\delta}$, we get to $W > n(1 + \bar{r})$. We assume $0 < \delta < \dfrac{1}{c}$ to ensure a positive discount rate. ∎

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Proposition 2. *An uncertainty-averse agent will invest in an incremental innovation if* $W > n(1 + r)$.

Proof. As an investment in incremental innovation does not imply uncertainty, we get this inequality by assuming $\delta = 0$ (due to $\chi = 0$). ∎

Alternatively, the Proposition above holds for an uncertainty-neutral agent investing in a breakthrough innovation.

Proposition 3. *Breakthrough innovations are less likely to be chosen by uncertainty-averse agents. This effect is stronger as volatility increases.*

Proof. It is easy to see that the inequality in Proposition 2 determines a less demanding condition for the investment to be chosen than the one in Proposition 1. Hence, Knightian uncertainty-aversion induces behavior where the innovator discounts by a hurdle rate $\bar{r}$ that exceeds the risk-free rate r .

The effective discount factor is adjusted upwards by a factor $\dfrac{1}{1 - c\delta}$ that accounts for a measure of uncertainty aversion (c) times a measure of the worst scenario loss (δ), that captures volatility.

Alternatively, we can say that, in order to induce the introduction of a breakthrough innovation, the expected revenues should exceed the risk-free yield by a premium proportional to the aversion to uncertainty times a measure of the dispersion of the random profit variable. This equation predicts that an increase in the range of possible returns will make investment in path-breaking innovations less likely: the LHS of the equation is not modified, while the RHS goes up. In these circumstances, higher volatility will reduce investment in breakthrough innovations. If the uncertainty is large, breakthrough innovations will not take place. ∎

Let's turn to the analysis of the welfare generated by breakthrough and incremental innovations.

If all firms are uncertainty-averse and share the same uncertainty aversion index c , the number of capital goods ($\overline{N}$) is determined by

$$\overline{N} = \frac{W}{1 + \bar{r}}$$

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

$$N = \frac{W}{1 + r}$$

with $N > \overline{N}$ as $0 < (1 - c\delta) < 1$. Therefore, uncertainty reduces the number of new activities. We now evaluate innovators' aggregate utility in case of breakthrough innovations:

$$\overline{U} = \Pi_0 + \frac{\chi \overline{N} W'}{1 + \bar{r}} - 0.5\overline{N}(1 + \overline{N})$$

(5)

where $W' = (w)^{-\alpha'} k L_Z$ (L_Z denotes labour in the final good Z). In case of incremental innovations we get

$$U = \Pi_0 + \frac{N W'}{1 + r} - 0.5N(1 + N)$$

(6)

The impact of uncertainty is evaluated by comparing the two previous expressions.

Proposition 4. *Investing in breakthrough innovations reduces uncertainty-averse agents' utility. The reduction increases as uncertainty and the vagueness of information increase.*

Proof. We compute the difference between the entrepreneur's utility in case of breakthrough innovation and the entrepreneur's utility in case of incremental innovation and approximate this expression around the non-stochastic equilibrium where the number of capital good is small and the uncertainty is large:

$$\frac{\overline{U}-U}{\frac{NW'}{1+r}-0.5N(1+N)} = \frac{\Pi_0 + \dfrac{W'[(\chi-0,5)\overline{N}-0,5]}{1+\bar{r}} - \Pi_0 + \dfrac{0,5W'(N-1)}{1+r}}{\frac{NW'}{1+r}-0.5N(1+N)} =$$

$$\frac{(1-c\delta)\left[\dfrac{W'(1-c\delta)}{1+r}\right]^2 - 0,5\left[\dfrac{W'(1-c\delta)}{1+r}\right]^2}{0.5\left[\left(\dfrac{W'}{1+r}\right)^2 - \dfrac{W'}{1+r}\right]} +$$

$$-\frac{0,5\dfrac{W'(1-c\delta)}{1+r} + 0,5\left[\dfrac{W'}{1+r}\right]^2 - 0,5\dfrac{W'}{1+r}}{0.5\left[\left(\dfrac{W'}{1+r}\right)^2 - \dfrac{W'}{1+r}\right]}$$

$$=\frac{\left[(1-c\delta)^2(0,5-c\delta)-0,5\right]\left[\dfrac{W'}{1+r}\right]^2 + 0,5\dfrac{c\delta W'}{1+r}}{0.5\left[\left(\dfrac{W'}{1+r}\right)^2 - \dfrac{W'}{1+r}\right]}$$

$$=\frac{-2c\delta\left[\dfrac{W'}{1+r}\right]^2 + 2\dfrac{c\delta W'}{1+r} - \dfrac{3}{2}\dfrac{c\delta W'}{1+r}}{0.5\left[\left(\dfrac{W'}{1+r}\right)^2 - \dfrac{W'}{1+r}\right]} \approx -4c\delta - K$$

where $\quad K = \dfrac{\dfrac{3}{2}\dfrac{c\delta W'}{1+r}}{0.5\dfrac{W'}{1+r}\left[\dfrac{W'}{1+r}^2 - 1\right]} = \dfrac{3c\delta}{\dfrac{W'}{1+r}-1} > 0 \quad$. The drop in the innovator's utility is proportional

to the uncertainty embodied in the investment, being determined by the degree of uncertainty aversion (measured by c) and by the range of possible outcomes (measured by δ), that can also be interpreted as vagueness of the information. ∎

To gain further insight on the relevance of uncertainty aversion, it is useful to contrast the behavior described above to the conduct of a conventional risk-averse Bayesian firm facing the same situation. If all firms are alike, risk aversion alone implies no differences in utility between investing in incremental or breakthrough innovations. 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 utility private "costs" of the

uncertainty related to a path-breaking innovation.

Let us turn to evaluate the costs of uncertainty in terms of labour income.

In case of breakthrough innovations, the labour income equals

$$\bar{I} = \frac{w\bar{\Lambda}}{1 + \bar{r}}$$

where Λ indicates the sum of aggregate labour in the intermediate goods x_i and in the final good Z respectively, i.e. $\Lambda = NL_n + L_Z$. As above, $\bar{\Lambda}$ represents the aggregate labour in case of a path breaking innovation, with $\bar{\Lambda} = \bar{N}L_n + L_Z$.

In case of incremental innovations, the aggregate labour income equals

$$I = \frac{w\Lambda}{1 + r}$$

Proposition 5. *Investing in breakthrough innovations reduces aggregate labour income.*

Proof. As $\bar{N} < N$ and $\bar{r} > r$, we get $\bar{I} < I$. ∎

The GDP is given by the sum of labour and entrepreneur income[5]. Therefore, when breakthrough innovations are introduced, the net income equals

$$\bar{Y} = \frac{w\bar{\Lambda}}{1 + \bar{r}} + \frac{\chi\bar{N}W'}{1 + \bar{r}} - 0.5\bar{N}(1 + \bar{N}) \tag{7}$$

In the presence of incremental innovations, the net income equals

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[5]In the Neo-Schumpeterian models setup, consumers' surplus is not affected by the increase in the number of goods: the whole consumers' surplus is extracted by monopolistically competing firms producing capital goods.

$$Y = \frac{w\Lambda}{1+r} + \frac{NW'}{1+r} - 0.5N(1+N)$$

$$(8)$$

As both labour and entrepreneur income is reduced by the combined effect of the uncertainty and vagueness (as shown above), we can conclude that path-breaking innovations might determine a drop in welfare when agents exhibit uncertainty aversion.

3.2 Breakthrough innovations with loss-averse agents

As discussed above, loss aversion might affect agents decisions in case of breakthrough innovation. Loss aversion is the tendency of agents to be more sensitive to reductions in their wealth than to increases in their wealth, where reductions and increases are relative to a reference point. We follow Gul (1991) and Aizenman (1998) in modelling an agent who maximizes a weighted sum of utility, where the weights deviate from the probabilities in order to reflect loss aversion. The preferences of a loss-averse agent may be summarized by $[U(x), \beta]$ where U is the conventional utility function of wealth x and $\beta \geq 0$ is a parameter measuring the degree of loss aversion. Let us denote by $V(\beta)$ the expected utility of a loss-averse agent who attaches extra disutility to circumstances where the realized income is below the "status quo" income. In the case of radical innovation, the producer attaches extra disutility to a realized profit that is below Π_0. The loss-averse expected utility equals the conventional expected utility (that here is additionally weighted by c in order to account for uncertainty aversion), adjusted downwards by a measure of loss-aversion times the expected loss:

$$V(\beta) = c\Pi + (1-c)E_u(\Pi) - \beta[V(\beta) - \Pi]$$

$$(8)$$

Proposition 6. *A loss-averse agent invests in a breakthrough innovation if* $W > n(1 + \hat{r})$.

Proof. In the absence of any investment in innovation, firm's profit are Π_0 . A loss-averse agent will invest in a breakthrough innovation if $V(\beta) > c\Pi_0 + (1-c)\Pi_0$, where

$$V(\beta) = c\left[\Pi_0 + \frac{(1-\delta)(w)^{-\alpha'}kL}{1+r} - n\right] + (1-c)\left[\Pi_0 + \frac{(w)^{-\alpha'}kL}{1+r} - n\right]$$

$$- \beta\left[V(\beta) - \Pi_0 - \frac{(1-\delta)(w)^{-\alpha'}kL}{1+r} + n\right]$$

that leads to $(w)^{-\alpha'}kL > n(1+\widehat{r})$. If we label $\widehat{r} = \dfrac{r + c\delta - \beta(1-\delta)}{1 - c\delta + \beta(1-\delta)}$ and $1 + \widehat{r} = \dfrac{1+r}{1 - c\delta + \beta(1-\delta)}$, we get to $W > n(1+\widehat{r})$. ∎

Proposition 7. *Breakthrough innovations are less likely to be chosen by loss-averse agents. This effect is stronger as volatility increases.*

Proof. It is easy to see that the inequality in Proposition 7 determines a more demanding condition for the investment to be chosen than the one in Proposition 1. The effective discount factor is adjusted upwards by a factor $\dfrac{1}{1 - c\delta + \beta(1-\delta)}$ that, as before, accounts for a measure of uncertainty aversion times a measure of the worst scenario loss $(-c\delta)$. Furthermore, this factor accounts for a measure of loss aversion (β) *per se* and for a measure of loss aversion times a measure of the worst scenario loss $(-\beta\delta)$. As β increases, the hurdle rate increases and the firm is less likely to invest in innovation. Loss aversion induces behavior where the innovator discounts by a hurdle rate that - again - exceeds the risk free rate and also exceeds the hurdle rate $\bar{r}$. In fact, discount factor $\widehat{r}$ is adjusted downward by a factor proportional to the combined effect of the measures of loss aversion (β) times losses deriving from unsuccessful innovation $(1-\delta)$. When $\beta = 0$, $\widehat{r} = \bar{r}$. ∎

If all producers share the same uncertainty aversion index c and the same loss aversion index β, the number of capital goods ($\widehat{N}$) is determined by

$$\widehat{N} = \frac{W}{1+\widehat{r}}$$

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Let's turn to the analysis of the welfare generated by breakthrough and incremental innovations when we account for loss aversion.

We now evaluate innovators' aggregate utility in case of breakthrough innovations:

$$\widehat{U} = \Pi_0 + \frac{\chi \widehat{N} W'}{1 + \widehat{r}} - 0.5 \widehat{N}(1 + \widehat{N}) \tag{9}$$

where $W' = (w)^{-\alpha'} k L_Z$ (L_Z denotes labour in the final good Z).

The impact of loss aversion is evaluated by comparing the two previous expressions.

Proposition 8. *Investing in breakthrough innovations reduces loss-averse agents' utility more than uncertainty-averse agents' utility.*

Proof. We compute

$$\frac{\widehat{U} - U}{\frac{NW'}{1+r} - 0.5N(1+N)} = \frac{\Pi_0 + \frac{W'\left[(\chi - 0,5)\widehat{N} - 0,5\right]}{1+\widehat{r}} - \Pi_0 + \frac{0,5W'(N-1)}{1+r}}{\frac{NW'}{1+r} - 0.5N(1+N)}$$

$$= \frac{[1 - c\delta + \beta(1-\delta)]\left[\frac{W'[1 - c\delta + \beta(1-\delta)]}{1+r}\right]^2}{0.5\left[\left(\frac{W'}{1+r}\right)^2 - \frac{W'}{1+r}\right]} +$$

$$- \frac{0,5\left[\frac{W'[1 - c\delta + \beta(1-\delta)]}{1+r}\right]^2 + 0,5\frac{W'[1 - c\delta + \beta(1-\delta)]}{1+r}}{0.5\left[\left(\frac{W'}{1+r}\right)^2 - \frac{W'}{1+r}\right]}$$

$$- \frac{+0,5\left[\frac{W'}{1+r}\right]^2 - 0,5\frac{W'}{1+r}}{0.5\left[\left(\frac{W'}{1+r}\right)^2 - \frac{W'}{1+r}\right]}$$

$$= \frac{0,5\left[\frac{W'[1 - c\delta + \beta(1-\delta)]}{1+r}\right]^2 + 0,5\frac{W'[1 - c\delta + \beta(1-\delta)]}{1+r}}{0.5\left[\left(\frac{W'}{1+r}\right)^2 - \frac{W'}{1+r}\right]} +$$

$$+ \frac{0,5\left[\frac{W'}{1+r}\right]^2 - 0,5\frac{W'}{1+r}}{0.5\left[\left(\frac{W'}{1+r}\right)^2 - \frac{W'}{1+r}\right]}$$

$$= \frac{-2[c\delta - \beta(1-\delta)]\left[\frac{W'}{1+r}\right]^2 + 2\frac{[c\delta - \beta(1-\delta)]W'}{1+r}}{0,5\left[\left(\frac{W'}{1+r}\right)^2 - \frac{W'}{1+r}\right]} +$$

$$- \frac{\frac{3}{2}\frac{[c\delta - \beta(1-\delta)]W'}{1+r}}{0,5\left[\left(\frac{W'}{1+r}\right)^2 - \frac{W'}{1+r}\right]}$$

$$\approx -4[c\delta - \beta(1-\delta)] - H$$

where $\quad H = \dfrac{\frac{3}{2}\frac{[c\delta - \beta(1-\delta)]W'}{1+r}}{0.5\frac{W'}{1+r}\left[\frac{W'}{1+r}^2 - 1\right]} = \dfrac{3[c\delta - \beta(1-\delta)]}{\frac{W'}{1+r} - 1} > 0 \quad$. As above, the expression is derived by

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computing the difference between the entrepreneur's utility in case of breakthrough innovation and the entrepreneur's utility in case of incremental innovation when loss-aversion is at work, and is approximated around the non-stochastic equilibrium where the number of capital good is small and the uncertainty is large. ∎

The drop in the innovator's utility is proportional to the uncertainty embodied in the investment, being determined by uncertainty aversion (measured by c), by the range of possible outcomes (measured by δ) and the degree of loss aversion β: crucially, β interacts with the worst scenario loss δ.

Let us turn to evaluate the costs of loss-aversion in terms of labour income.

In case of breakthrough innovations, the labour income equals

$$\widehat{I} = \frac{w\widehat{\Lambda}}{1 + \widehat{r}}$$

where $\widehat{\Lambda}$ represents the aggregate labour in case of a path breaking innovation, with $\widehat{\Lambda} = \widehat{N}L_n + L$.

Proposition 9. *With loss-averse agents, investing in breakthrough innovations reduces aggregate labour income more than uncertainty-averse agents' labour income.*

Proof. As $\widehat{N} < N$ and $\widehat{r} > r$, we get $\widehat{I} < I$. ∎

Loss-aversion effect adds to uncertainty effect in reducing labour aggregate income.

As above, the GDP is given by the sum of labour and entrepreneur income. Therefore, when breakthrough innovations are introduced and agents are loss-averse, the net income equals

$$\widehat{Y} = \frac{w\widehat{\Lambda}}{1 + \widehat{r}} + \frac{\chi\widehat{N}W'}{1 + \widehat{r}} - 0.5\widehat{N}(1 + \widehat{N})$$

$$(10)$$

As both labour and entrepreneur income is reduced by the combined effect of the uncertainty aversion, vagueness and loss aversion, we can conclude that path-breaking innovations determine a further drop in welfare when agents exhibit loss aversion in addition of uncertainty aversion.

3.3. The effects of innovators' experience and substitutability among capital goods on welfare

This section presents two exercises of comparative statics in the aim of studying the effects on welfare of an increase in innovators' experience and in the degree of competition in the market respectively.

Proposition 10. *An increase in innovators' experience levels increases the welfare generated by breakthrough innovations.*

Proof. A way of capturing the role of innovators' experience in the model is assuming that an expert innovator is able to reduce the vagueness of the possible outcomes related to a path-breaking innovations. Therefore, an expert innovator faces a lower value of δ . Let us evaluate the impact of δ on loss-averse agents' discount rate by computing the following derivative:

$$\frac{\partial(1+\hat{r})}{\partial\delta} =. \frac{-(c+\beta)(1+r)}{[1-c\delta+\beta(1-\delta)]^2} < 0$$
. Expert innovators faces a lower hurdle rate.

Let us evaluate the sign of $\dfrac{\partial \widehat{Y}}{\partial \delta}$. We get $\dfrac{\partial \widehat{Y}}{\partial \delta} = -(c+\beta)[2A(1-c\delta+\beta-\beta\delta)+B] < 0$ with
$A = wWL_n + W'W + 0.5(W')^2 > 0$ and $B = wL + 0.5W' > 0$. ∎

Therefore, the higher the experience level, the lower the value of δ and the higher the welfare amount.

Proposition 11. *A lower degree of substitutability among capital goods decreases the welfare generated by breakthrough innovations.*

Proof. Higher substitutability implies a higher level of α . Let us evaluate the impact of α by first investigating the impact of loss aversion (captured by the hurdle rate $(1+\hat{r})$) in shaping welfare, whose value positively depends on w and $\widehat{N}$ (see above).

We compute the following derivatives:

$$\frac{\partial \log[w]}{\partial \log[1+\hat{r}]} = -\frac{1-\alpha}{1+\alpha} \quad \text{and} \quad \frac{\partial \log\left[\widehat{N}\right]}{\partial \log[1+\hat{r}]} = -\frac{1}{1+\alpha} .$$

and find that both derivatives increase as α increases. ∎

If the new capital good introduced by means of a breakthrough innovation has a low degree of

substitutability with the existing capital goods and satisfies very specific production needs, a reduction in social welfare occurs.

4. Discussion and conclusions

Being aware of the determinants that shape the decision between small ameliorements of the existing technology and path-breaking innovations helps in delineating practices to stimulate specific types of innovative projects. Everybody says that breakthrough innovation 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 breakthrough innovation might eventually make their course shorter, less sporadic, less expensive, and less uncertain.

Nonetheless, from a welfare point of view, path-breaking innovations might be inferior to incremental innovations. This paper stresses 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 attributable 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.

The paper explains the reluctance to open new technological trajectories by showing that, if agents are uncertainty and loss averse, both aversions may interact, potentially magnifying the welfare costs of uncertainty and losses related to a path-breaking innovation. A decision in favour of a cumulative development of the existing technology, as in case of incremental innovation, is far to be suboptimal for an uncertainty and loss averse agent.

The paper presents a Neo-Schumpeterian model that accounts for the introduction of new goods and captures the related sunk costs. The analysis grounds on Aizenman (1997)'s work that investigates the

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effect of uncertainty aversion when a multinational firm modifies the set of capital goods by introducing a new one whose production is located in a developing country (where uncertainty in production costs is high). The present paper enlarges the analysis by accounting for loss aversion, that plays a major role in path-breaking innovations, as they imply the abandonment of the existing technology and possible consequent losses. Knightian uncertainty and loss aversion characterize breakthrough innovations as opposed to incremental innovations where only measurable uncertainty is involved. Interestingly, the setup allows for two exercises of comparative statics. Path-breaking innovations are more frequently introduced by expert innovators who better predict the possible outcomes of the investment and deal with a reduced amount of vagueness. This results reflects the empirical finding in Conti, Gambardella & Mariani (2010). Furthermore, a lower degree of substitutability among capital goods decreases welfare. A possible interpretation is that the disruptiveness of a path-breaking innovation, captured by scarce substitutability between the new capital good and the ones used in the existing production process, enhances the loss in welfare that occurs in presence of uncertainty and loss aversion.

References

Abernathy, W. and Clark, K.B. (1985). Mapping the winds of creative destruction. *Research Policy*, 14, 3-22.

Adams, M.E., Day, G.S. and Dougherty, D. (1998). Enhancing new product development performance: An organizational learning perspective. *Journal of Product Innovation Management,* 15(5), 403-422.

Aizenman, J. (1997). Investment in new activities and the welfare cost of uncertainty. *Journal of Development Economics*, 52, 259-277.

Aizenman, J. (1998). Buffer stock and precautionary savings with loss aversion. *Journal of International Money and Finance*, 17, 931-947.

Arrow, K. (1962). Economic welfare and the allocation of resources for inventions In: Nelson R. (ed.). *The Rate and Direction of Innovative Activity.* Princeton University Press: Princeton.

Arthur, B.W., Ermoliev, Y.K. and Kaniovski, Y.K. (1987).Path-dependent processes and the emergence of macro-structure. *European Journal of Operational Research*, 30 (3), 294-303.

Banerjee, P. M. and Campbell, B. A. (2009). Inventor bricolage and firm technology research and

development. *R&D Management*, 39, 473--487.

Battaggion, M.R. and Grieco, D. (2009). Radical innovation and R&D competition. *Rivista Italiana degli Economisti*, 2, 345-359.

Baumol, W.J. (2004). Education for innovation: Entrepreneurial breakthrough vs. corporate incremental improvements. *NBER*.

Bester, H. and Petrakis, E. (1993). The incentives for cost reduction in a differentiated industry. *International Journal of Industrial Organization,* 11, 519-534.

Bjorn-Anderson, N., EarI, M., Holst, O. and Mumford, E. (eds) (1982). *Information Society: For Richer, For Poorer.* Amsterdam: North-Holland and Publishing Company.

Bonanno, G. and Haworth, B. (1994). On the choice between process and product Innovation. Papers 94-16, California Davis - Institute of Governmental Affairs.

Caballero, R. (1991). On the sign of the investment-uncertainty relationship. *American Economic Review*, 81(1), 279--88.

Cardinal, L.B. (2001). Technological innovation in the pharmaceutical industry: the use of organizational control in managing research and development. *Organization Science*, 12(1), 19-36.

Choi, J.P. (1994). Irreversible choice of uncertain technologies with network externalities. *Rand Journal of Economics*, 594-605.

Conti, R., Gambardella, A. and Mariani, M. (2010). Learning to be Edison? How individual inventive experience affects the lielyhood of breakthrough inventions. *Mimeo.*

Delbono, F. and Denicolò V. (1991). Incentives to Innovate in a Cournot Oligopoly. *Quarterly Journal of Economics*, 951-961.

Dewar, R.D. and Dutton J.E. (1996). The adoption of radical and incremental changes: An empirical analysis. *Management Science*, 32(11), 1422-1433.

Dosi, G. (1988). *Technical Change and Economic Theory.* Burns & Oates.

Doraszelski, U. (2004). Innovations, improvements, and the optimal adoption of new technologies. *Journal of Economic Dynamics & Control*, 28,1461 -- 1480.

Duchesneau T.D., Cohn, S.F. and Dutton, J.E . (1979) A study of innovation in manufacturing: Determinants, processes, and methodological issues. Social Science Research Institute, University of Maine at Orono.

Ellie, J. E. (1983). Organizational policy and innovation among suppliers to the food processing sector.

Academy of Management Journal, 26 (1), 27-44.

Ellsberg, D. (1961). Risk, ambiguity, and the Savage axioms. *Quarterly Journal of Economics*, 75 (4), 643--669.

Farell, J. and Soloner, G. (1985). Standardization, compatibility, and Innovation. *Rand Journal of Economics*, 16, 70-83.

Fleming, L. (2001). Recombinant uncertainty in technological search. *Management Science*, 47(1), 117-132.

Freeman, C. and Soete, L. (1997). *The Economics of Industrial Innovation.* Routledge, Oxon, UK.

Garcia, R. and Calantone, R. (2002). A critical look at technological innovation typology and innovativeness terminology: A literature review. *Journal of Product Innovation Management*, 19(2), 110-132.

Geroski, P.A. (1995). What do we know about entry? *International Journal of Industrial Organization*, 13, 421-440.

Gilbert, R.J. and Newbery, D.M. (1982). Preemptive patenting and the persistence of monopoly. *American Economic Review*, 72, 251-253.

Gilboa, I. and Schmeidler, D. (1989). Maxmin expected utility with non-unique prior. *Journal of Mathematical Economics*, 18(2), 141-153.

Gul, F. (1991). A theory of disappointment aversion. *Econometrica*, 59, 667-686.

Hage, J. (1980). *Theory of Organization: Form, Process and Transformation.* Wile: New York.

Hamermesh, D.S. and Pfan, G.A. (1996). Adjustment Costs in Factor Demand. *Journal of Economic Literature*, 34(3), 1264-1292.

Hartman, R.S., Doane, M.J. and Woo, C. (1991). Consumer rationality and the status quo. *Quarterly Journal of Economics*, 106 (1), 141-162.

Henderson, R. (1993). Underinvestment and incompetence as responses to radical innovation: Evidence from the photolithographic alignment equipment industry. *Rand Journal of Economics*, 24, 248-270.

Henderson, R.M. and Clark, K.B. (1990). Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly*, 35, 9-32.

Jones, L.E. and Manuelli, R. (1990). A convex model of equilibrium growth. *NBER* Working Papers

3241, National Bureau of Economic Research

Kahneman, D., Knetsch, K.L. and Thaler, R.H. (1991). Anomalies: The endowment effect, loss aversion, and status quo bias. *Journal of Economic Perspectives*, 5(1), 193-206.

Kaluzny, A., Veney, J.E. and Gentry , J.T. (1972). Innovation of health services: A comparative study of hospitals and health departments. *Quarterly Health Society*, 52(1), 51--82.

Katz, M.L. and Shapiro, C. (1985). Network externalities, competition and compatibility. *American Economic Review*, 75, 424-440.

Klump, R. (1998). Competition and growth: A macroeconomic perspective, in A. Haid, D. Mueller, J. Weigand (eds). Competition, Efficiency, and Welfare: Essays in Honor of Manfred Neumann. Dordrecht/Boston/London, 329-340.

Kuhn, T.S. (1970). The structure of scientific revolutions.

Leifer, R., Colarelli O'Connor G. and Rice M. Implementing radical innovation in mature firms: The role of hubs. *Academy of Management Review*, 3, 102-113.

Lucas, R.E. (1988). On the mechanisms of economic development. *Journal of Monetary Economics*, 22 (1), 3-42.

Lundvall, B.A. (1992). (ed.). *National Systems of Innovation: Towards a Theory and Interactive Learning*. London, Pinters Publishers.

Nord, W.R. and Tucker, S. (1987). *Implementing Routine and Radical Innovations*. Lexington Books: Lexington, MA .

O'Connor, G.C. (1998). Market learning and radical innovation: A cross case comparison of eight radical innovation projects. *Journal of Product Innovation Management*, 15(2), 151-166.

Rebelo, S. (1991). Long-run policy analysis and long-run growth. *Journal of Political Economy*, 99(3), 500-521.

Romer, P. M. (1986). Increasing returns and long-run growth. *Journal of Political Economy*, 94, 1002-1038.

Romer, P. M. (1987). Growth based on increasing returns due to specialization. *American Economic Review*, 7(2), 56-72.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, 98 (5), 71-102.

Romer, P. M. (1994). The origins of endogenous growth. *Journal of Economic Perspectives*, 8(1), 3-22.

Salant, S.W. (1984). Preemptive patenting and the persistence of monopoly: Comment. *American*

Economic Review, 74(1) 247-250.

Samuelson, W. and Zeckhauser, R. (1991). Status quo bias in decision making. J*ournal of Risk and Uncertainty*, 1(1), 7-59.1091.

Sorescu, A., Chandy, R. and Prabhu, J. (2003). Sources and financial consequences of radical innovation. *Journal of Marketing*, 66, 82-102.

Witt, U. (1997). Lock-in' vs. 'critical masses': Industrial change under network externalities. *International Journal of Industrial Organization,* 15, 753-773.