INNOVATION AND COMPETITION: A SURVEY

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This paper surveys the theoretical and empirical studies that in the Schumpeterian tradition investigate the interactions between innovation and competition. In the theoretical part, first, I illustrate the most important strand of literature in this field (Industrial Organization models); then I focus on general equilibrium models. Empirical studies have attempted to quantify the effects of different degrees of competition on innovation. Until the late nineties, theoretical insights were at odds with empirical findings. In the last ten years theoretical and empirical results have begun to converge, although many issues remain unresolved.

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Contents

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1. Introduction

A vast literature has investigated how market structure affects the innovative activity of firms. How one affects the other remains an open question. The title of a recent paper by Schmutzler (2010) is: *The relation between competition and investment (in R&D): Why is it such a mess?* It records the high sensitivity of the theoretical results to modelling choices. Empirical studies shed only partial light on the reasons why.

Competition (domestic and/or international) can be a driver of productivity by enhancing innovation. Some degree of monopoly could in some cases foster innovation (by sustaining rewards for successful innovators), while excessive protection for incumbents could discourage potential innovative outsiders. The (neo) Schumpeterian synthesis links competition and innovation in a non-monotonic shape depending, amongst other things, on the degree of firms' technological rivalry and on their distance from the technological frontier (Aghion and Griffith, 2005; Aghion et al., 2005 and 2009).

This paper focuses on the effects that competition has on incentives to innovate, referring primarily to the theoretical contributions from the most important strand of literature in the field, namely the Industrial Organization models. It also reviews the results obtained by the empirical literature that investigates the causal relationship between competition and innovation. I leave out many theoretical and empirical results from some fields of literature that are very close to the one we are dealing with. Examples include the theoretical contributions on the links between competition and growth that date back to the propositions formalized by Adam Smith in the first fundamental theorem of welfare economics; the well-known empirical studies on the relationship between regulation and productivity that gained momentum recently, in particular following the studies promoted by the OECD (see, for example, Arnold et al., 2011; Nicoletti and Scarpetta, 2003); the macroeconomic works on the relationship between changes in regulation and productivity (e.g. Blanchard and Giavazzi, 1991); the studies on competition and employment (e.g. Viviano, 2008); the pro-competitive effects of trade (e.g. Melitz and Ottaviano, 2008; Bugamelli et al., 2010). I shall not survey the literature on the indicators adopted to gauge innovation and competition, since others have already done excellent work on this (recently on competition, Boone, 2008a and 2008b).

This paper is organized as follows. Section 2 describes the tangled relationships between competition, innovation and productivity. Section 3 gives a simplified version of the taxonomy developed by De Bondt and Vandekerckhove (2012), referred to theoretical models in industrial organization literature (single classes of models are described more extensively in subsections), and surveys general equilibrium models. Section 4 is dedicated to the empirical literature and is divided into old, new and structural empirical literature. Section 5 concludes.

2. Competition, innovation and productivity: untangling the knots

Innovation and competition are complex phenomena. The importance of their relationship lies, on one side, in the uncontested proposition that sees innovation as the engine of growth (see e.g. Schumpeter 1942, Romer 1990, Aghion and Howitt 1992, 1998, Grossman and Helpman 1989, 1991, 1994). On the other side, in the Schumpeterian proposition that sees competition as one of the crucial determinants of innovative activity. What follows is an attempt of unraveling the tangle of the links between competition, innovation and productivity.

Competition can affect productivity mainly through three channels.

The first two refers to the concept of static efficiency[2] in its aspect of, allocative and productive efficiency.

1. Allocative efficiency refers to the first fundamental theorem of welfare economics: perfect competition is Pareto optimal.. The situation in which a firm or an industry allocates optimally its resources is achieved through the price of a product being related to its marginal cost of production.[3]
2. Productive efficiency refers to the situation in which a firm or an industry is producing at its production possibility frontier and at its lowest possible average cost, producing the maximum output from a given set of inputs. Office of Fair Trading (2007). In this context, competition drives productivity through two mechanisms (Vickers, 1995; Nickel 1996)

   a. *Within firm* effect: competition places pressure on the managers of firms to increase internal efficiency (x-efficiency). This highlights the importance of competition enforcement to ensure that firms and their managers are subject to the rigor of the market (Holstrom 1982; Hart, 1983; Schmidt, 1997 with bankruptcy threat; Nickell, 1996).

[2] How much output can be produced from a given stock of resources at a certain point in time.

[3] As well known this theoretical result is based on restrictive hypothesis: price taking, no natural monopolies and oligopolies, no barriers to entry/exit, perfect information, etc.

b. *Between firm effect*: competition ensures that higher productivity firms increase their market share at the expense of the less productive. These low productivity firms may then exit the market, and are replaced by higher productivity firms (Hopenhayn, 1992). There is strong empirical evidence of these processes and their effects on productivity. It refers to the entry/exit dynamics (Geroski, 1991) and from a very recent point of view, it determines it determines a selection among firms with heterogeneous productivity levels: "*competition moves market shares toward more efficient producers, forcing the exit of low efficient producers and also raising the bar that any potential entrant must meet to enter*" (left-truncated productivity distribution: see Syverson, 2011; Melitz, 2003; Melitz and Ottaviano 2008).

3. A further aspect is related to dynamic efficiency: it is the rate at which firms reduce their real costs, or improve their product quality over time and it refers to the innovative process. Innovation increases dynamic efficiency and productivity through technological improvements of production processes, or the creation of new products. This mechanism operates therefore through the incentives to innovate and revolves around three main effects:

    a. the discouragement effect (Schumpeter, 1942): high competition can be detrimental to innovation. The rapid disappearance of ex-post rents from innovation, discourages ex-ante the innovative activity;

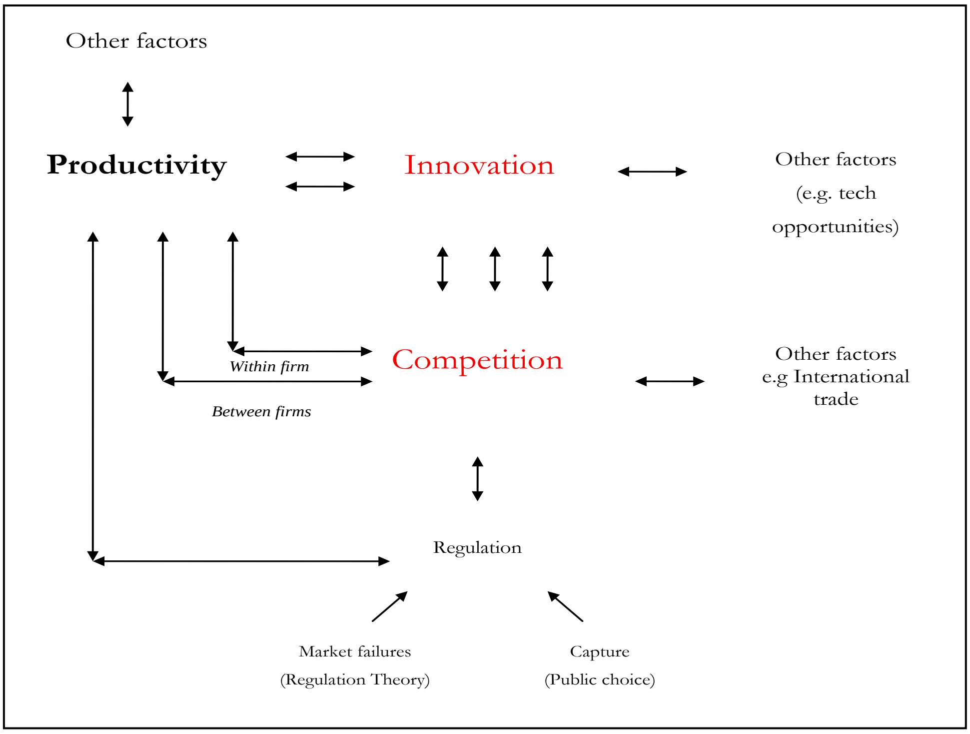
    b. the replacement effect: Arrow (1962), points out that the monopolist has less incentive to innovate than the firm in competition. The monopolist would replace a rent that already has while the firm under a regime of competition would not displace any monopoly profit and would gain the full return of innovation[4];

    c. potential or actual competition can induce an incumbent leader to react to the competition threat and to innovate in order to maintain its leadership. This incentive (*escape competition effect*) would not work be if the leader were too protected (Aghion et al, 2005).

Figure 1 below tries to sum up the links described. In the next paragraphs we will focus only on the relationships between the red labels.

When we talk about innovation and competition we are definitely in a strictly Schumpeterian ground. On one side, we implicitly adopt Schumpeter's point of view that has influenced most of the theories of innovation, where he argued that economic development is innovation-driven, through a dynamic process in which new technologies replace the old, a process he called "creative destruction". On the other side, Schumpeter itself stressed on two determinants of the innovative activity, firm size and market structure, arguing that some degree of monopoly could in some cases foster innovation (by sustaining the reward of successful innovators).

Figure 1. Innovation, competition and productivity



Obviously the degree of competition is only one of the possible economic variables that affect innovation and, according with many authors, it is not the most important one. This explains why a huge part of the literature and many economists, in particular many of those who focus on the 'economics of innovation', devoted little attention to the innovation-competition link (see Rosenberg and Hall, 2010). Nonetheless, there is a very large body of works, going back to Schumpeter and continuing with Arrow (1962) and many other scholars that analyzed the effect of competitive pressure on the innovative effort.

The question at stake, formulated many years ago, is: does more competition stimulates or hampers innovation? Nowadays the question seems of utmost importance because at least two well known reasons.

[4] Schumpeter refers to competition in the post innovation market while Arrow refers to pre-innovation competition.

First, there is the necessity of a deep understanding of the impact that the globalization process, with its raising the international competition, had and will have on the incentives to innovate (Bugamelli Fabiani Sette, 2010). Second, in particular within the European and Monetary Union, removing of barriers to entry in many sectors, raising competition through the liberalization of industry and services are addressed as the main growth enhancing policies to follow (Barone e Cingano, 2011; Sestito and Torrini, 2012).

One of the most interesting points of the subject, as we shall also see below, is the disconnection between theory and empirics that prevailed until recently, that seemed to be fixed in the last ten years but that recently has emerged again in the form of an extremely wide range of conclusions reached by theory and empirical works.

Long time has passed since the early contribution of Schumpeter (1942) and Arrow (1962), still, no general consensus has emerged: "*Any kind of relationship appears to be theoretically possible*" (Peneder and Worter, 2011, p.2).

3. Theoretical models: a taxonomy.

This section reviews industrial organization models that deal with the relationship between competition intensity and innovative activity. What follows is not far from being a "survey of surveys" (with some updating) since many scholars already made excellent reviews (Gilbert, 2006; Cohen, 2010; De Bondt and Vandekerckhove, 2012). Thus, in the rest of the paper I will borrow shamelessly from their works starting from the taxonomy that follows, that is a reduced version of the one proposed by the latter authors (Figure 2).

A clear parting is made between *decision-theoretic models* (which mainly go back to the 1970s, assume that the intensity of rivalry is exogenous, constant and not affected by any other firm's R&D investment decisions) and *game-theoretic models* (in which strategic interaction prevails). The latter can be partial or general equilibrium models. Among partial equilibrium models, a distinction is made between the so called *stochastic patent races* and *strategic investment models* (static or dynamic). Competition is mainly formalized with the degree of *product differentiation* or with the *numbers of firms*.

3.1 Decision-Theoretic Models

In DT models firms take their decisions maximizing their profits independently from the decision the other firms are likely to adopt. The reference model is Kamien and Schwartz, (1976) (but see also Scherer, 1967; Loury, 1976).

In Kamien and Schwartz (1976), firms compete on innovation by choosing the optimal introduction date T (so called *development period*) that maximizes the expected present value of an innovation. Firms invest in R&D in order to be the first to innovate and "win" the patent that is awarded to the earliest innovator. The intensity of competition is formalized as the probability of being pre-empted by a rival since the more intense the rivalry, the sooner rival innovation is expected.

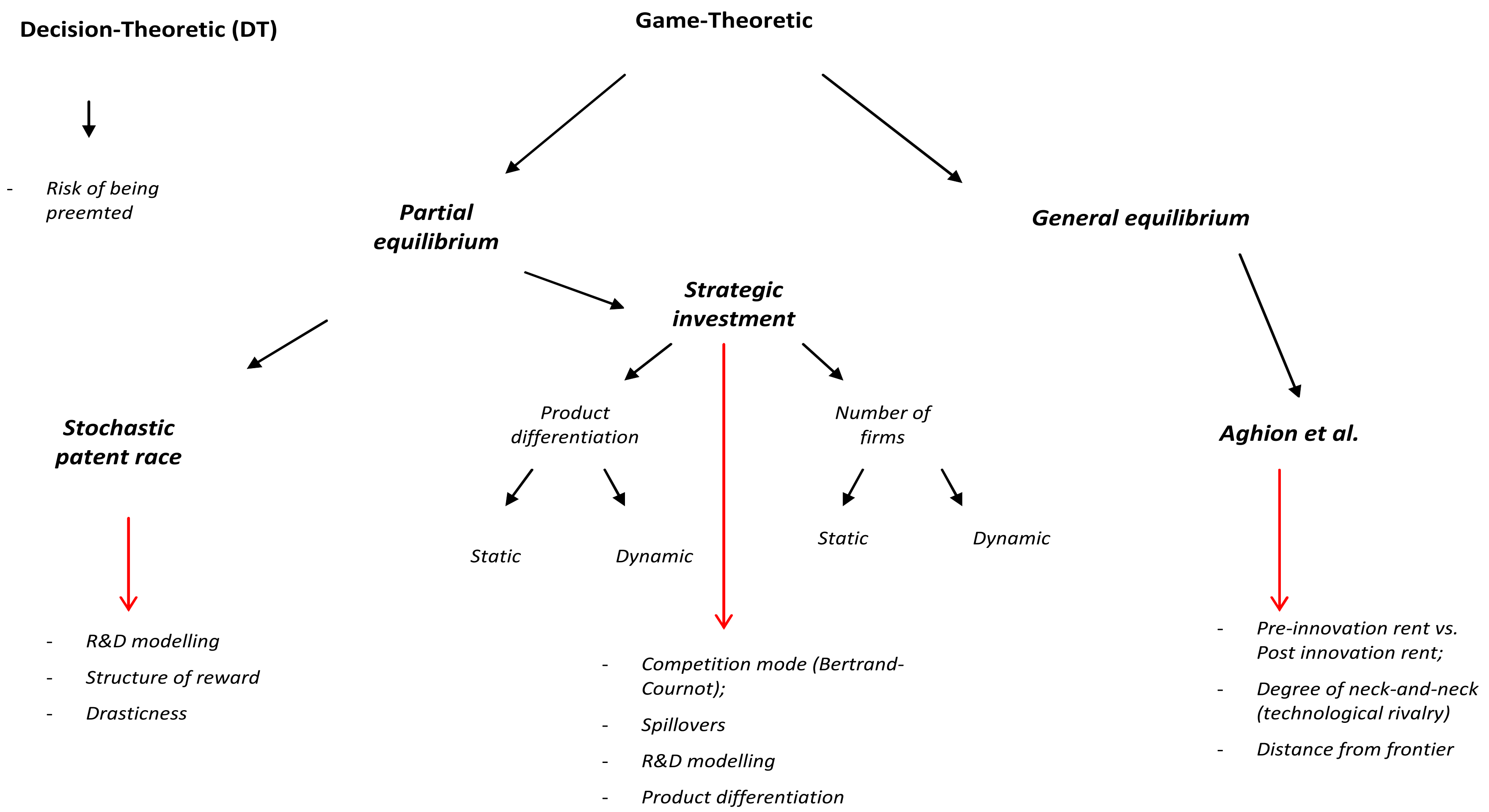
What is the effect of a different degree of rivalry on the incentives to invest in R&D? In a zero rivalry context, a firm optimal R&D rate depends on the difference between the amount saved not investing in R&D and the implicit costs of postponing the investment. Delaying the investment in innovation lowers the present investments expenditure but also lowers the discounted value of the rewards (De Bondt and Vandekerckhove, (2012, p.9).

More intense rivalry increases the cost of postponement because it raises the probability of preemption and thus raises the effort in innovation. However, when this probability is large (i.e, the rival innovation is expected to arrive sooner), efforts are reduced. "*We have demonstrated analytically the possible existence of an intermediate intensity of technological rivalry that is most stimulating for innovative activity"* (Kamien and Schwartz, 1976, p. 258).

So, what is the mechanism at work? In a context where R&D is designed to reduce the cost of production (process innovation), the risk of being preempted induces a defensive innovative effort. Can not go unnoticed that the conclusions of this early model are exactly in line with the inverted-U shape relation found in newer models, where the risk of being pre-empted is replaced by the *competition threat* effect.

Figure 2 (see De Bondt and Vandekerckhove, 2012)

Competition and Innovation: Industrial Organization Models



3.2 Partial Equilibrium Game-Theoretic Models

We have seen that in the decision-theoretic models rivalry is exogenous. Game theoretic models assume strategic interdependency of firms' R&D decisions. The sign and the intensity of the relationship between investments in innovation and the degree of competition, depend on many factors: the static vs. dynamic nature of the game; whether R&D is modeled as fixed vs. variable cost; the mode of competition (Bertrand vs Cournot); the nature of innovations (incremental vs. radical); the structure of rewards (winner-takes-all vs. a leader-follower pattern).

One of the first attempts to model the effects of competition on R&D in a game-theoretic model is found in Scherer (1967). He shows that, up to some point more rivalry leads to greater R&D expenditures, but if rivalry becomes too strong, one can expect its post-innovation rents to be insufficient to repay R&D costs and this does not stimulate R&D. Once again, an inverted-U relationship emerges.

Following the scheme in Figure 2, we have the following three cases

a. Partial Equilibrium Models: Patent Race

In *patent race models* firms aim to be the first to innovate and win the patent (for a complete overview of the patent race literature: Reinganum, 1989). Differently from the DT models, the risk of being pre-empted by a rival is endogenous and determined by the rivals' R&D investments. An example of this class of models is Loury (1979)'s. In this model, the race for patents is symmetric (firms decide simultaneously on R&D investments) and winner-takes-all (i.e., patenting provides perfect protection for the innovator). Firms maximize their expected profits and invest in R&D under uncertainty (the relationship between a firm R&D and the time at which innovation will be introduced, both for the firm itself and for its rivals, is stochastic). The main findings are that increasing the extent of rivalry reduces each firm incentive to invest in R&D. So, individual firms' R&D investments are negatively related with the number of firms[5]. Moreover, this general result is dependent on some assumptions: 1) the modeling of R&D as a flow (+) or lump sum (-) cost[6]; 2) The degree of reward sharing[7]; 3) the drasticness of the innovation[8]. The table below (Table 1) summarizes the main results.

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[5] Since rivalry is endogenous, increasing the number of competitors reduces the expected time that society has to wait for the innovation, despite the fact that each competitor invests less (Loury, 1979: 402)

[6] If modelled as flows, (Lee and Wilde, 1980), more rivalry (number of firms) stimulates R&D expenditure. In case of lump sum R&D costs, an increase in the number of rivals lowers each firm's R&D because lowers the expected benefits from investing in R&D as each firm is less likely to win the race but expected costs remain unaffected.

Table 1. Competition and Innovation in *Patent Race* models

	R&D modeling		Patent protection		Nature of innovation	
	Flow	*Lump sum*	*Winner-takes-all*	*Reward Sharing*	*Drastic*	*Non drastic*
Relationship between n. firms and firm R&D	+	-	+	-	+	-

b. Partial Equilibrium Models: Strategic Investment

This class of models is typically based on a two stage game. In the first stage a 'strategic' decision on R&D investments (that will generate process or product innovation[9]) is taken. This decision will affect the subsequent market competition (formalized with Cournot or Bertrand competition), with homogeneous or differentiated products. The decision of investing in R&D is, (differently from DT-models) *non-tournament*: all the firms that invest in R&D win (obtain innovation and cost reduction) and the R&D production function is deterministic so that a certain level of R&D input gives a known R&D output.

In strategic investment (either static or dynamic) the level of competition is alternatively formalized with the number of firms in the market or with the degree of product differentiation[10].

[7] Stewart (1983) states: "the positive relation between the number of firms and individual R&D efforts only applies when the patent provides a sufficiently strong protection of the innovation (winner-takes-all): if all profits accrue to the firm that makes initial discovery, then an increase in rivals research would lead our firm to increase its research as well. When the degree of reward sharing is large, a larger number of potential innovators discourages firms to invest in R&D.

[8] Innovation is drastic when allows the innovator to impose a monopoly price. An increase in the number of firms might, under certain conditions, discourage individual firms' R&D investments, when firms compete for a non-drastic innovation (see Delbono and Denicolò, 1991; De Bondt and Vandekerckhove, 2012: 11).

[9] Boone (2000) analysed the effects of competition on the effects on investments in product and process innovation

[10] "The concept of product market competition cannot be measured directly but only by resorting to the use of various proxies. Proxies for an increase in competition intensity in theoretical models include: a switch from Cournot to the "more competitive" Bertrand competition; a switch from a monopoly to a duopoly (more generally, an increase in the number of firms: Arrow, 1962; Gilbert and Newbery, 1982; Tirole, 1988; Boone, 2001); an increase in the substitutability among differentiated products (Tang, 2006), a reduction of transport costs, a decline in market concentration (Tirole, 1988), a decline in firm profitability (Aghion et al., 2005 use the Lerner index), and more. For a discussion of these and other measures of competition, see Tirole (1988), Boone (2001, 2008a, 2008b) and Tang (2006)". Tishler and Milstein (2009), p. 519.

b.1. Degree of product differentiation in Strategic Investment Models

In static strategic investment models (SSI), the relation between the degree of product differentiation and the level of R&D investments tends to be negative. Competition operates through four direct effects that affect the incentives to invest in R&D (Qiu, 1997):

- negative *cost* effect: the more R&D is costly, the less is the investment in R&D (independently with respect to Bertrand or Cournot competition);

- positive *size* effect (independent from competition mode, Bertrand or Cournot): the higher the firm output, the higher its willingness to invest in R&D (exactly in line with the Schumpeterian thought). The mechanism that lies behind is the *cost spreading* one: see Cohen and Klepper, 1996);

- the negative *spillover* effect (more appropriability reduces the ex post advantages: again, a pure Schumpeterian effect);

- the *strategic* effect, positive in Cournot and negative in Bertrand competition, because in the latter context, there is the risk of triggering a downward price war[11].

The strength of size (+), spillover (-) and strategic (-/+) effects, depends on the degree of product differentiation as in Table 2 below:

Table 2. R&D incentives in Strategic Investment Models:
How the degree of product differentiation affects the *cost, size, spillover* and *strategic* channels
(plus or minus)

	Cost	Size	Spillover	Strategic
Bertrand	-	+	-	-
Cournot	-	+	-	+
Impact of less differentiation	*Unaffected*	*Reduces the positive effect*	*Strengthens the negative effect*	*Strengthens both Bertrand (-) and Cournot (+)*

More competition reduces the (positive) size effect since it lowers output per firm; enhances the (negative) spillover effect, since firms are more sensitive to free riding; strengthens the (negative-Cournot and the positive-Bertrand) strategic effects.

[11] In Bertrand-style competition, any innovation-driven reduction in production costs that results in a decrease in prices, induces other firms to cut prices as well. Consequently, in order to avoid such downward moves, a firm may opt for a reduction of its R&D investments (see De Bondt and Vandekerckhove, 2012:13).

So, in the end, this class of models predicts a positive effect of competition on innovation, only in the case of a Cournot competition by strengthening the (positive) strategic effect, when there are small spillovers and low size effects [12].

b.2. Number of firms in Strategic Investment models

De Bondt et al. (1992) analyzed the impact on R&D, of an increase of competition formalized with an increase in the number of firms. They used an SSI model with Cournot competition. More rivals affect negatively the individual incentive to innovate due to the dominance of the *size effect* stemming from the resulting drop in output per firm.

When the number of firms increases, it is interesting also to consider the impact on aggregate R&D that can have a different sign with respect to the impact on individual R&D, depending on the level of spillover and on the degree of product differentiation. The possible outcomes are reported in Table 3.

Table 3. R&D incentives in Strategic Investment Models:
How an increase in the number of firms affects innovation incentives (different scenarios)

		Cournot competition		*Bertrand competition*	
Degree of prod. differentiation	*Spillovers*	*Single firm*	*Total economy*	*Single firm*	*Total economy*
Low	*Low*	-	+	-	+
	High	-	-	-	-
Medium	*Low*	-	+	-	+
	High	-	∩	-	-
High	*Low*	-	+	-	+
	High	-	∩	-	+

Source: De Bondt and Vandekerckhove (2012), p. 15.

In this class of models, individual investments in R&D are always negatively affected by an increase in the number of firms, via the *size* effect. Total industry investments both with Cournot and Bertrand competition, are positively related with the number of firms when spillovers are small. With large spillovers, Cournot competition yields an inverted-U relation when products are highly or intermediately differentiated; in Bertrand competition, there's a positive relation

[12] An exception to this general result is the U-shaped relation in a static model with Cournot competition, when the spillover is small enough and products have low differentiation (see Tishler and Milstein 2009, p. 520, a two stage model to analyze the impact of the degree of product differentiation on the level of R&D investments: see Tishler and Milestein, 2009, p. 520. Lin and Saggi (2002), Sacco and Schmutzler (2010) and Schmutzler (2010) stress that the shape of the relation between the degree of product differentiation and R&D activity is highly dependent on the assumed competition mode and the spillover level, and the U-shaped relation results only the particular case we describe (Cournot competition, low spillovers).

between the number of firms and aggregate R&D investments only when products are highly differentiated (the high differentiation acts as a shield from the increase in the number of firms. See also De Bondt and Vandekerckhove, 2012, p.14)[13]

3.3. General Equilibrium Models

As Aghion and Griffith (2005) put it, the theoretical literature described in previous paragraphs predicts mainly negative effects of competition on innovation and growth because it adopts almost exclusively the Schumpeterian mechanism: more competition reduces the monopoly rents that reward successful innovators[14].

More recently, a new mechanism has been introduced: by affecting the incentive to innovate in presence of competition, it connects the Schumpeterian with the Arrowian points, bringing back to the hypothesis of non-linear relationship between innovation and competition and in particular to the inverted-U hypothesis[15]. The idea, that was introduced by Aghion-Harris-Vickers (1997) and subsequently extended in a variety of formulations (listed in footnote 15) reformulates a basic Schumpeterian model by allowing incumbents to innovate. They distinguish between *pre-*

[13] Vives (2008) gives a comprehensive analysis of the relationships between competition and innovation by using an SSI model that considers: two scenarios, with free entry (endogenous market structure) or restricted entry (exogenous market structure); three competition proxies: degree of product substitutability, number of competitors and entry costs; two kinds of innovations: process or product. The articulated set of results, they claims, could be a guide for empirical literature and for policy. As for product differentiation, Cellini and Lambertini (2010), propose a dynamic game in a Cournot style competition proxied by the number of firms. They found that the R&D investments monotonically increase in the number of firms, a result that contradicts the findings of static games. When looking at the effects of an increase in the number of firms on innovation, they obtain an Arrowian conclusion: aggregate R&D effort increases in the number of firms. As we have seen, on the contrary, if the intensity of competition is measured by product substitutability for a given market structure (i.e. for a given number of firms), then the model points to a Schumpeterian conclusion (in Bertrand competition).

[14] Also early endogenous growth models predicted a negative effect of competition on innovation. Competition reduces innovation by lowering the ex-post monopolistic rent and discouraging the effort in R&D: Romer, 1990; Aghion e Howitt, 1992; Grossman and Helpman, 1991 (quality ladder, i.e. quality improving innovations). Nonetheless, many empirical works, especially in the nineties (such as Geroski, 1991; Nickell, 1996; Blundell, Griffith and Van Reenen, 1999) pointed to a positive correlation between product market competition and innovative output. In order to reconcile theory and empirics, Aghion, Dewatripont e Rey (1999) introduce agency costs. They show that for firms with 'principal-agent' problems, higher competition acts as an incentive scheme for manager to invest more in quality improvement: competition and reduces the managerial slack (see also Machlup 1967 and Porter 1990). A further mechanism that radically changes the theoretical conclusions (Aghion, Harris and Vickers, 1995) is to modify the technological assumptions, assuming that technological progress by leaders and followers takes place *step-by-step* and not through automatic leap-frogging. This mechanism is at the heart of the Aghion et al. (2005, 2009) models of innovation and competition we are analysing in the present paragraph.

[15] The recent revival of interest in this kind of relationship can be attributed to the various studies of Aghion with different coauthors: Aghion P, Harris, Vickers (1997); Aghion P, Harris, Howitt P., Vickers (2001); Aghion P, Bloom N, Blundell R, Griffith R, Howitt P (2005); Aghion e Griffith (2005); Aghion and Howitt (2006), Aghion, Blundell, Griffith, Howitt, Prantl (2009). Actually, as we have seen, although the literature focuses mainly on this inverted-U

innovation and post-innovation rents, e introduce the notion of *escape* competition. More competition, by affecting both present and future profits, can raise the incentives to innovate by lowering the pre-innovation rent more than the post-innovation rent. So, an increase in product market competition can stimulate R&D by increasing the incremental profit from innovating, that is, by strengthening the incentive to innovate in order to escape competition. *Escape competition* can overlook *rent dissipation*, depending on the technological features of the sector/industry. In particular, it depends on the technological rivalry of the firms within the same industry and on the distance from the technology frontier.

The main prediction is that of an *inverted-U* shape relationship between competition and innovation[16]. This inverted-U is related to the endogenous fraction of the industries in which firms are technologically similar (called *neck-and-neck* or *leveled* industries). When there is only little market competition, the largest innovation activity is done by laggards and takes place in *unlevelled* industries where the post-innovation rent is high and laggards have incentives to innovate since the low competition guarantees an ex-post rent. In this case, the sectors tend to become *leveled*.

When the market is *mostly levelled,* an increase in competition results in larger innovative efforts due to the dominance of the *escape competition effect* (we are on the positive side of the inverted-U shape). Consequently, many of the industries will sooner o later return in an unleveled state, but, in a context of high competition (we now are on the downward side of the inverted-U). With this composition effect in mind, it is clear that a further increase in competition intensity reduces innovative investments because now laggards have low incentives to innovate since with a higher competition the Schumpeterian discouragement effect prevail. Leaders do not innovate too due to the shield of their technological predominance (Arrowian *rent dissipation effect*).

relationship, a U-shaped nonlinear relationship is found in Tishler and Milstein (2009), Scott (2009), Schmutzler (2010) or Sacco and Schmutzler (2010). See also Peneder e Worter (2011).

[16] Aghion et al. (2005) use a two-sector, two-firms framework firms that innovate in order to reduce production costs, and they do it "step-by-step": a laggard firm in any industry must first catch up with the technological leader before leapfrogging and becoming itself a leader. There are two kinds of industries: those called *levelled* where both firms have the same technology of production (called '*neck-and-neck*)'. *Unleveled* industries are instead characterized by competition between a leader and a follower. It is assumed that leaders can be ahead only one step and followers can only catch-up but not overtake the leader within one time period. In neck-and-neck industries competition is particularly effective in fostering innovation because the "escape-competition" effect is stronger. On the other hand, in more "unleveled" industries, in which firms face different production costs, high competition may dampen innovation as the laggard's reward to catching up with the technological leader may be very low (Schumpeterian effect) and for leaders, the rent dissipation effect prevails. So, an increase in the degree of competition has different effects on industry R&D in the two different kind of industries. In the leveled industries: an increase in PMC spurs R&D due to the escape competition effect. In the unleveled industries, only the laggard firms invests in R&D and incentives are reduced when competition is more intense due to the reduction in post-innovation rents (the Schumpeterian effect dominates on laggards and it overcome the escape competition of leaders).

Summing up, the key predictions of this step-by-step innovation model are the following. The relationship between competition and innovation is an inverted-U shape. The higher the average degree of *neck-and-neckness* of an economy (i.e. technological competition), the stronger the escape-competition effect will be on average, and therefore the steeper the positive part of the inverted-U relationship. The positive relationship is stronger when sectors are close to their technological frontier (in this case the escape competition effect is particularly strong[17]).

Last, in Aghion et al. (2013a), differently from other works (e.g., early endogenous growth models or Boldrin and Levine, 2008, that argued that patent protection is detrimental to innovation because it hampers product market competition), patent protection complements product market competition in encouraging R&D investments.

4. The empirical literature

4.1 Old Empirical Literature

The empirical literature on the relationship between market structure and innovation, especially the oldest one (Table 4), has been severely affected by many methodological drawbacks[18].

Following Gilbert (2006), a first wave of studies focused on the relationship between competition – measured using concentration indexes – and R&D spending or innovative output (see Table 4). These works, as a general tendency, found larger R&D intensity in moderately concentrated industries[19]; however, these result typically disappeared when controlling for industry effects.

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[17] In Aghion et al. (2005), competition is proxied by mark-ups or by a "collusion" coefficient. Aghion et al (2009), formalized competition with the new entrants: this generates an escape entry effect that acts as the escape competition of previous models. "We model the degree of product market competition inversely by the degree to which the two firms in a neck-and-neck industry are able to collude". Aghion et al (2005), p. 713.

[18] Cohen, (2010). Aghion and Griffith (2005) refer to: omitted variables in the identification of the relationship between innovation-competition; not adequate treatment of the reverse causality issue; lack of identification strategies based on exogenous variations as, for example, policy changes. Problems also arise from data (e.g., unavailability of panel data). Critics are often raised with respect to the proxies used to measure both competition and innovation (the latter are often indicators based on R&D expenditure or patents)

[19] An important part of these studies found a positive relationship. Horowitz (1962), Hamberg (1964), Scherer (1967), Mansfield (1968). Geroski (1990) rather than using an input (R&D) of the innovative process, they use an output: the counts of commercially significant innovations drawn from the SPRU database. Geroski (1991) uses also measures for competition different from concentration, as for example entry, exit, import penetration. He found a positive relationship between competition and innovation, a reversal of the majority of prior findings that he attributes to the inclusion of a control for technological opportunity in the R&D/innovation regressions

Scherer, (1965) using 448 firms on Fortune's list of the 500 largest U.S. industrial corporations for the base year 1955 (clustered in 56 industries) finds positive but very modest and statistically insignificant influence of the market share variable on patenting. Introducing a quadratic term for competition (market share) in order to test for nonlinearities, found a U-shaped relationship, with minimum patenting at the C4 concentration ratios (the share of the largest four firms in the industry) between 44 and 71 per cent. In contrast, Scherer (1967) found (new sample) an inverted-U shaped relationship, with maximum patenting at the C4 concentration ratio between 50 and 55 cent. Still one important result is common to both models: when industry controls are introduced, the explanatory power of concentration falls.

Comanor (1967) used a measure of minimum efficient scale (average plant size within each industry) as a proxy for the entry barriers created by scale economies. He found evidence that higher concentration, for given levels of firm size, is associated with greater research expenditure in some market situations. Mansfield (1981) found no indication that more concentrated industries devote larger percentages of R&D to basic research.

Link e Lunn (1984) data derive from a sample of 223 U.S. manufacturing firms. They separate process and product returns to R&D and find that process-related R&D are greater in more concentrated industries. The returns to R&D are related to the appropriability of the output from R&D which, in turn, is related to the strength of the property rights. Process-related R&D tends to produce output which is not easily patented, so firms find in the high concentration a way to prevent misappropriation (a sort of substitutability between PMC and property rights. See also Lunn, 1986: contrary, Aghion et al, 2013b).

Culbertson e Mueller (1984), uses firm level data from the food industry (also small firms; cross section 1970, 61 firms) They find an Inverted-U shape. Angelmar (1984) examine the behavior of high-tech opportunity firms (160 business observations in 1978). He examines the interaction between market concentration, barriers to imitation and R&D intensity. He found that concentration is positively related to R&D intensity in industries with low barriers to imitation; negatively related to R&D in industries with high barriers.

From the mid-1980s, a second wave of researches returned to the Schumpeterian hypothesis using somewhat more sophisticated econometric techniques and improved data.

Scott (1984) using Federal Trade Commission almost two thousand line of business data for 437 firms, found no significant inverted-U relationship between market structure and R&D intensity after controlling for firms and industries effects[20]. Levin et al. (1985) found (firm level) a

[20] Scott (1984) showed that fixed two-digit industry effects explained 32% of the variance in R&D intensity. The concentration ratio and its square explained 1.5 per cent.

statistically significant "inverted-U" relationship between industry concentration and R&D intensity. The relationship peaked at a C4 index (the share of the largest four firms in the industry) of about 0.5-0.6. Nonetheless, the inclusion of variables that measures technological opportunity[21] and appropriability for each firm lowered the significance of the concentration variables in the R&D regression.

So, a serious lack of robustness emerged when controlling for industry-specific characteristics suggesting deep differences across industries. This is, perhaps, the most persistent finding in the early empirical literature concerning the effect of concentration on R&D intensity. As Baldwin and Scott (1987) noted: "*The most common feature of the few R&D and innovation analyses that have sought to control for the underlying technological environment is a dramatic reduction in the observed impact of the Schumpeterian size and market power variables*." Gilbert (2006) gives a detailed list of the methodological issues at stake[22] and reaffirm that the statistical significance of competition (proxied by market concentration) disappears when accounting for the degree of appropriability, the technological opportunities and the demand conditions.

The importance of the distinction between product and process innovation has been somewhat neglected. These categories imply different effectiveness of intellectual property rights, (Levin et al. 1987); differences in innovation incentives (Link and Lunn, 1984 found that the returns to *process-R&D* increased with market concentration while the returns to *product-R&D* were independent of market concentration).

Technological opportunities are also critical to incentives for R&D and can differ greatly across industries and across time[23], while quasi-natural experiments are very few[24].

[21] Defined as the easiness of successfully innovating, for any given amount of invested resources.

[22] The list is long. Some of the most important relates to the limits faced when using R&D or patents as proxies for innovation. For example, innovations often come from unexpected sources, including from firms in unrelated industries and sometimes from individual inventors. Market concentration as a proxy for competition can be misleading since competition doest not depend (only) on the number of firms; it depends on costs, quality, brand recognition, barriers to entry, on characteristics of demand, managers motivation. Furthermore, market concentration can be endogenous to innovation. Successful innovation by a firm that is far from the technological frontier can create new competition by closing the cost or product quality gap relative to the market leader, even though the size structure of the industry may appear to be the same in both cases. See Gilbert (2006).

[23] See Crepon, Duguet and Mairesse (1998). Technological opportunity is about the possibility of converting an innovation into a new enhanced product or production process. Many researchers have realized the importance of this concept, although still lacking a clear and precise understanding of how to conceptualize and measure it. Geroski (1991b) argues that industries in the early phase of the product cycle may be characterized by high rates of innovation and a high level of technological opportunity which stimulates R&D. Often, technological opportunity is treated as an unobservable industry component. Dosi (1982), Nelson and Winter (1982) stress on three principal sources of technological opportunity: advances in scientific understanding and technique, technical advances originating in other industries and institutions, and feedback from an industry's own technical advances.

[24] Carlin, Schaffer, and Seabright (2004), examine firm-level performance following the privatization of State-owned enterprises in 24 transition countries. They find evidence of the importance of a minimum level of rivalry in both innovation and output growth. Firms innovated more after the privatization event in markets exposed to foreign

At last, unobserved, latent influences that end up in the "error term," could be major determinants of innovative outcomes. "*When we think of innovation, we think of individuals that may be not observable in some sense.* […]. *They exhibit flashes of brilliance, choose a different path, and push the frontiers of technological progress. We must be careful not to suppress the role of the true innovators by burying them in the econometric error term"* (Gilbert, 2006, p. 199).

4.2. New Empirical Literature

The more recent empirical literature (Table 5), supported by theory, up-to-date methodologies and data availability, made important improvements. The non-linear relationship between competition and innovation (a hypothesis, as we have seen in the previous section, that is anything but new. See Scherer, 1967), lies often at the heart of the investigation.

Aghion et al (2005) use an unbalanced panel of 311 UK firms listed on LSE, matched with NBER patent database: seventeen industry two-digit SIC code from 1973-1994 (354 industry-year observations: 17 industries for 21 years). The innovation variable is the citation-weighted patent index (yearly average) within each industry, while the competition index is the Lerner index (operating profit-financial costs)/sales) or price-cost margins (see Boone, 2008a and 2008b). The econometrics is based on a non linear estimator (Poisson regression).

A sequence of competition policy reforms (privatization events, changes in merger policies, the introduction of the European Union single-market program), are used as instruments to control for the potential endogeneity between innovation and competition.

A focal point of their analysis (as in their model) is the technological rivalry and the distance from technological frontier. To capture the degree of technological rivalry within each industry (degree of *neck-and-neckness*) they construct a measure of the size of technology gap based on the dispersion of firm level technology and cost indicators[25]. In a nutshell, the main results are the following (see also Figure 3): an inverted-U relationship between competition and innovation; the peak of the inverted-U lies near the median value of the Lerner index; the ascending part of the

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competition. They also found evidence that the presence of a few rivals was more conducive to innovative performance than the presence of many competitors, suggesting an inverted-U relationship between innovation and competition.

[25] Aghion et al. (2009) use also measures of foreign direct entry to estimate the relationship between patenting and market competition. They find that foreign direct entry had very different effects on the innovation conduct of firms, depending on the current performance of the industry in which they operate. Firms in industries that had the same productivity growth of the U.S. tended to increase innovation in response to entry while lagging industries did not and sometimes innovated less in response to foreign entry. They argue that technologically progressive firms arte more able to "escape" the negative effects of entry by innovating.

curve is steeper for sectors/industries where the technological rivalry is higher (more neck-and-neck) or where firms are closer to their technological frontier.

Many other works are consistent with these findings.

Tingvall and Poldahl (2006), use Swedish firm-level data covering the Swedish manufacturing industry spanning the period 1990–2000 (all manufacturing firms with at least 50 employees). They find evidence of an inverted-U relationship using Herfindal index the finding of an inverted-U shaped relation is sensitive to the choice of both the competition and innovation indicators: sensitive to either the choice of competition measures or the innovation indicator[26].

Lee (2009) uses a World Bank survey for nine industries across seven countries. The intensity of competition is proxied by the degree of market pressure perceived by each individual firm in both the domestic and global markets. Firm's R&D response to market pressure depends primarily on its level of technological competence: firms with high levels of technological competence[27] tend to respond aggressively (i.e., exhibit a higher level of R&D efforts) to intensifying competitive market pressure; firms with low levels of technological competence tend to respond submissively (i.e., exhibit a lower level of R&D efforts).

Alder (2010) elaborates data based on a survey from 40 developing and transition countries (firm level). He found that firms with more advanced technology compared to their main competitors have more product innovations, although the correlation between competition, innovation and the technological level is unclear.

Van der Wiel (2010) gets his data from the survey Produktie Statistiesken (firms with more than 20 employees, 1993-2006) and the Community Innovation Survey (CIS, the European harmonized survey held every two years, containing questions about innovative activities in enterprises), covering the period 1996-2006. Using an index of innovation intensity (expenditure on innovation divided by the number of employees) as a measure of innovation and the survey-based measures of competition, he found statistically significant inverted U-curve in manufacturing (but not a steeper upward part of the inverted-U curve due to more neck-and-neckness).

In many papers the results are more fragile and negative effects of competition on innovation are not unusual. Artés (2009), uses data from the Spanish Survey of Business' Strategies (ESEE),

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[26] The relationship turns negative with price-cost margin index. Controlling for fixed effects, the relation between competition and R&D becomes insignificant.

[27] Technological competence represents the degree of easiness in the production of quality. (see Dosi and Teece, 1993). It is difficult to find an appropriate operational variable for the analytically defined measure of firm-specific technological competence. The World Bank data set provides a good proxy variable for technological competence, which measures the level of technological capability of individual firms relative to the world technological leader in their field, rated on a five-point scale.

conducted from 1990 to 2002[28]. He finds that competition affects long-run R&D decisions (investing or not) but does not affect short-run ones (how much invest). The relation between R&D and market structure is weak after controlling for how it is easy is for the companies to appropriate the results of their R&D efforts or for technological opportunities and heterogeneity across industries. Monopoly power (mark-up or market share) is associated with a higher probability of firms becoming R&D doer. Using the concentration ratio, an inverted U-shape relationship emerges. After controlling for industry and market characteristics, appropriability, the relation between R&D intensity and market structure vanishes.

With the same dataset (30,466 observations: 4,094 firms over the period 1990-2006), Santos (2010) found that competition (measured with the number of competitors or market shares), has negative effects on product innovation and no effects on process innovation. Czarnitzki et al. (2011) use a unique dataset and survey for the German manufacturing sector, the Mannheim Innovation Panel (it is the German part of the CIS[29]). They find that entry threat has a different impact according with the leadership position[30]: market leaders do invest in R&D more than other firms when they are under the competitive pressure of endogenous entrants[31].

Tang (2006) showed that a fast pace of technological change (e.g. rapid arrival of novel products and production technologies) has a positive effect on R&D while high competition (proxied by perceived substitutability of products) has a negative impact.

Finally, Tishler and Milstein (2009), Schmutzler (2010), Sacco and Schmutzler (2009, 2010) support, under certain conditions, a U-shaped relationship between competition and innovation. Their studies are not econometric estimates: the former use a model-based numerical simulation and the latter base their paper on a laboratory experiment. But nonetheless, their findings do find support in many other empirical studies (e.g., Peroni and Gomes Ferreira, 2012, find a negative impact of competition and innovation with a positive quadratic term).

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[28] He uses several indicators of product market competition: concentration ratio; price-cost margin; market share (a dummy = 1 if the firms reports that there are less than ten companies with significant market share in the main product market, or a dummy = 1 if the firm reports to have a significant market share and 0 otherwise

[29] They use instrumental variables to deal with competition (entry) endogeneity Differently from Sutton (1998), (he used the size of the median plant in an industry as a proxy for minimum efficient scale, and instrument therefore for the size of the costs of entry), they use the degree of substitutability between goods (from survey answer)

[30] They find that R&D intensity of the average firm is lower when there is an endogenous entry threat compared to when there is not. R&D intensity of the incumbent leader is larger than the investment of the average firm when there is an endogenous entry threat.

[31] Coherently, Vickers (1986) found that with Bertrand (lighter) competition, low cost firms innovate while with Cournot (tougher) competition, only high cost firms innovate.

4.3 Structural models of innovation

Few variables are truly exogenous determinants of innovation, nonetheless, few statistical studies of innovation use structural economic models that are in principle able to solve the issue. Empirical studies often make a clear case that market structure affects R&D, but there is little doubt that R&D is a cause of market structure, and this endogeneity complicates the analysis (see Crepon Duguet and Mairesse 1998; Peneder e Worter, 2011; Hall, Lotti and Mairesse, 2012, Amable et al, 2012: see Table 5).

A point that must be stressed, however, is that the main goal of this class of models is, in most cases, not to study competition but rather the links between R&D, innovation and productivity. Hence, in structural models of innovation, competition is often a bit player.

Crépon, Duguet and Mairesse (1998: CDM) used a 1990 French Survey with information about the innovation output (sales from innovative product), demand conditions and technological opportunities and they found a positive relationship between market shares and R&D. In this line of research, Amable et al. (2010) use a sample of 13 manufacturing industries for 12 OECD countries during the 1980-2003. R&D and patenting intensity are the two alternative measures of innovative performance; EU KLEMS for data; patenting from EUROSTAT; Product Market Regulation indicators constructed by the OECD. They find that the marginal effect of PMR on patenting intensity tends to be positively and growing with the closeness to the technological frontier.

Castellacci (2013) addresses directly the competition-innovation relationship and, using the CDM model, finds that in more concentrated (oligopolistic) industries, firms have a higher propensity to engage in innovation, where firms in competitive industries are characterized by a stronger impact of the innovation inputs on their performance.

Peneder e Worter (2011)[32] use a panel of Swiss manufacturing firms (28 industries and, within each industry, three firm size classes) observed across five periods (1999, 2002, 2005, and 2008) with at least five employees covering all relevant industries in the manufacturing. They propose a simultaneous system of three equations. Their results are coherent with Aghion et al (2005): they find a robust inverse-U relationship, where a higher number of competitors increases

[32] The authors formulate a critique of the game theoretic models since these models offer testable implications only in their over-simplified version ("most stripped down version"). For example, many of these models analyze the competitive process with one incumbent and one entrant. Many results also depend on strong assumptions about the distribution of information, the sequence of actions. On close inspection, they say, (p. 6) "the specific theoretical framework of Aghion et al. (2005) cannot be truly transposed to the micro-econometric setting of our analysis".

the firm's innovation effort, but at a diminishing rate. The inverse-U shape is steeper for creative than adaptive entrepreneurial regimes.

Amable, Ledezma e Robin (2012), explore the idea that the intensification of PMC in upstream service sectors would press large oligopolists to allocate resources more efficiently and to innovate (the so called "knock on effect". Barone and Cingano, 2011, examine the knock on effect on productivity). The study is based on a structural model of innovation, and conducted at the industry level and find no evidence of a positive effect of competition. Hall, Mairesse, Lotti (2012) using the Unicredit (one of the most important Italian commercial bank) survey, find that international competition is positively related to R&D intensity.

5. Conclusions

Are we still in a mess? Undoubtedly some progress has been made with respect to the nineties when theory (focused on the Schumpeterian mechanism) was often at odds with empirical findings (which in turn were prone to severe technical problems).

The theory has made advancements recognizing, among other things, that the Schumpeterian (discouragement) effect is not the sole mechanism affecting innovation. As is to be expected (and hoped for) new theoretical insights have opened up new fields of analysis and have highlighted some novel aspects deserving further investigation. In fact, the main "new" aspect is not new at all and represents a return to the past: the non-linear shape of the relationship between competition and innovation.

As far as the empirical literature is concerned, increased data availability has allowed many methodological problems to be resolved and the proxies used to gauge competition have also been refined.

Nonetheless, both theoretical and empirical results are still lacking robustness. In theoretical models, non-linearity can take the form of a U or of an inverted U, depending on the modelling strategies and on model assumptions. Econometric studies deliver different results according to the different data and indexes of competition used.

An important part of the recent literature finds that more competition promotes innovation mainly when the initial degree of competition is low, the level of technological rivalry is high, and firms are closer to the technological frontier. However, also on these points, empirical studies produce a variety of results and have not yet reached unanimous conclusions.

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Table 4. Old empirical literature

Authors	Innovation	Measure of Competition	Data	Econometrics	Results
Scherer, 1965	R&D, patents,engineers and scientists	Marker concentration ratio (C4)	448 firms, Fortune's list of the 500 largest U.S., 1955, grouped in 14 industries	OLS	U-shape with minimum patenting at 44% <C4< 71%
Scherer, 1967	R&D, patents,engineers and scientists	Marker concentration ratio (C4)	56 industry groups covering nearly all of U.S. manufacturing industry for 1960	OLS, industry controls	Inverted U-shape[33] with maximum patenting at 50% <C4< 55%
Comanor, 1967	R&D personnel	Concentration index, technical barriers to entry (minimum efficient scale	Cross section, firms grouped in 21 industries	OLS	R&D intensity is greater where barriers to entry are moderate
Mansfield, 1967	R&D expenditure (composition), innovation (survey)	Marker concentration ratio (C4)	Cross section, 100 firms grouped in 12 industries	OLS	No association between more concentration and innovation
Scott, 1984	R&D expenditure per unit of sales (R&D intensity)	Marker concentration ratio (C4)	3388 manufacturing lines of business of the 437 firms (FTC data) grouped in industries	OLS, industry fixed effects	Concentrated industries spent less on basic research; concentration had no significant effect on R&D.
Link e Lunn, 1984	Rate of return to R&D	Marker concentration ratio (C4)	223 U.S. manufacturing firms.	OLS	Returns to process R&D increased with concentration. Returns to product R&D independent of concentration.

[33] A more detailed list of the “old” empirical works can be find in Gilbert (2006)

Authors	Innovation	Measure of Competition	Data	Econometrics	Results
Culbertson e Muller, 1985	R&D employment, expenditure; patents	Marker concentration ratio (C4)	Food manufacturing industry	OLS	Positive correlation with concentration up to a threshold C4 = 60%.
Levin et al, 1985	R&D expenditure, intensity; innovation (survey)	Marker concentration ratio (C4)	Food manufacturing industry	OLS + controls for appropriability and technological opportunity	No effect of concentration on R&D once controls are considered
Anglemar, 1985	R&D expenditure	Market concentration, barriers to entry	High-tech opportunity firms (160 business observations in 1978)	OLS	Concentration positively related to R&D intensity in industries with low barriers to imitation, negatively related to R&D in industries with high barriers to imitation.
Lunn, 1986	Patents	Market concentration-ratio (C4)	Firms (FTC data) grouped in 191 industries (4-digit SIC)	2SLS	Process patents in low-tech industries positively related to concentration. No effect of concentration on product patents, or process patents in high-tech industries.
Geroski (1990 and 1991)	Data on significant innovation introduced in UK, 1945-1983	Market concentration (C5), market share.	Data on innovations ; industry cross-section panel. Period; 1970-4 and 1975-9	Tobit	Almost no support in the data for popular Schumpeterian assertions about the role of actual monopoly in stimulating innovation.

Table 5. New empirical literature and structural models

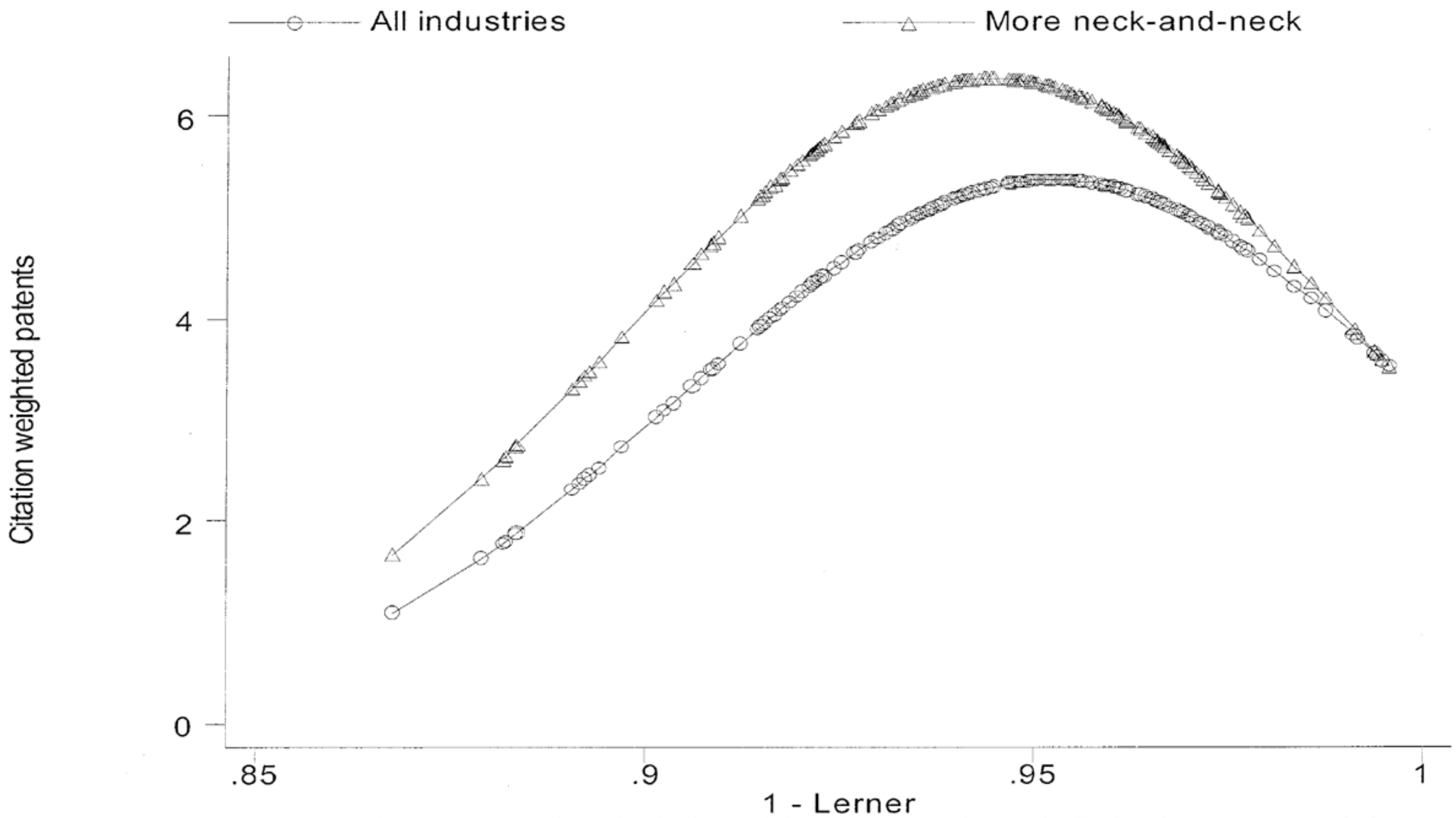
Authors	Innovation	Measure of Competition	Data	Econometrics	Results
Crépon et al. (1998)	R&D per employee	Market share	1990 French Survey – 6145 manufacturing firms	(Structural model) OLS/ML, industry dummies	Competition and R&D intensity are negatively correlated
Blundell, Griffith, Van Reenen, 1999	Numbers of innovation, patents	Market share; product market competition	Firm level; SPRU and USPTO; 3551 observations from 340 manufacturing firms	Dynamic count data model IV (lags)	Market share (+) (pre-emptive) Product market competition (-)
Bassanini and Ernst (2002)	R&D intensity	PMR	Industry at 2 digit level (ISIC Rev.3) and 18 countries	OLS with country and industry dummies	More competition in the product market -- while guaranteeing intellectual property rights --has positive impact on the innovation performance of a country.
Carlin, Schaffer, and Seabright (2004)	Innovation measure (survey based)	Number of competitors, market power (survey based)	Survey EBRD/AC Nielsen; 3,837 firms, 24 transition countries	Large-scale natural experiment	Market power enhances innovation but some rivalry ensures efficient use of resources
Aghion et al (2005)	Citation-weighted patents	Lerner index	311 UK firms 1973-1994 unbalanced panel of 354 industry-year observations (17 industries times 21 years	Poisson regression. semiparametric moment estimator	Inverted-U shape relation between competition an innovation
Tang (2006)	Survey based	Four types of innovation perceptions	Statistics Canada innovation Surveys,	Multinomial logit	Product substitutability (–) Rate of obsolescence: (+) or (–) New competing products (+) Rate of tech. change (+)
Tingvall and Poldahl (2006)	R&D	Herfindal index; mark-up	Firm-level data, Swedish manufacturing industry 1990–2000 (at least 50 employees); 2258 obs.	OLS, 2SLS, Prais-Winsten	Inverted-U with H-index, but not with mark-up
Aghion et al (2009)	Citation-weighted patents	Greenfield foreign firm entry rate	Unbalanced panel 1073 obs. on 174 firms in 60 three digit industries, 1987-1993	Poisson regression. semiparametric moment estimator	Inverted-U shape relation between competition an innovation
Artés (2009)	R&D	Concentration ratio, price-cost margins, market share, dicotomic survey-based	Spanish Survey of Business' Strategies (ESEE); 1990-2002	Probit (Conditional Maximum Likelihood dynamic random effects probit model)	The probability of conducting R&D increases with monopoly power; the intensity of R&D is unaffected.

Lee (2009)	R&D intensity	Perceived market pressure	World Bank Survey	OLS	The higher the technological competence, the higher the R&D response to an increase in competition.
Amable et al. (2010)	Patenting intensity	PMR index	Country-imdustry panel data. 5 industries for 17 OECD countries over the period 1979-2003	GMM	PMR positively related to Patents: more at the leading edge (interaction term)
Alder (2010)	Product innovation measure (survey based)	Market power index (survey based)	World Bank firm level survey, 2002-2008; 40 developing and transition countries; 9000 obs.	OLS (country-time-indutry controls), Probit	Inverted-U relationship (not for all measures of mkt power)
Santos (2010)	R&D, Innovation measures (survey based)	Number of competitors; market shares	Spanish Survey of Business' Strategies (ESEE); 1990-2002 30,466 observations for 4,094 firms	FE, GMM	Competition (number of competitors) is negatively correlated with product innovation; no relation with R&D decisions
Van der Wiel (2010)	Innovation measure (survey based)	Herfindal index; Produce market competition and Price Elasticity[34]	Dutch firm level data: Produktie Statistieken (1993 to 2006) survey and the Community Innovation Survey	GMM	Inverted-U (but the positive part is not stepper with more neck-and-neck)
Peneder e Worter (2011)	Innovation measure survey based	Survey based (principal competitors in the main product market)	Panel of Swiss firms observed across five periods (1999, 2002, 2005, and 2008	Structural model, 3-SLS	Robust and nonlinear inverted-U shaped effect of competition on innovation
Czarnitzki et al. (2011)	R&D	Entry threat, leadership (survey based)	Mannheim Innovation Panel Survey (German manufacturing sector) and CIS	Tobit	Endogenous entry threats reduce R&D intensity for the average firm, but increase it for an incumbent leader
Amable, Ledezma e Robin (2012)	Patent intensity (patents/hour woked)	PMR index	EU KLEMS; EUROSTAT PATENS; OECD; Balanced panel; 12 countries; 13 industries; 1980-2003; 3744 obs.	Structural model	More regulation foster leaders innovation; hinders followers.
Hall, Mairesse, Lotti (2012)	R&D intensity (expenditure per employee)	Survey based (presence of competitors, National or international)	Frim survey – Unicredit – unbalanced panel; 14,294 obs.; 9850 firms	Augmented-CDM OLS (Industry, wave, regional, and time dummies)	International competition affects positively R&D intensity

[34] Percentage fall in profits due to a percentage increase in marginal costs

Figure 3. Aghion et al. (2005)

1A: Innovation and Competition: The Neck and Neck Split



The figure plots a measure of competition on the x-axis again citation weighted patents on the y-axis. Each point represents an industry-year. The circles show the exponential quadratic curve that is reported in column (2) of TABLE I. The triangles show the exponential quadratic curve estimated only on neck-and-neck industries that is reported in column (4) of TABLE III.