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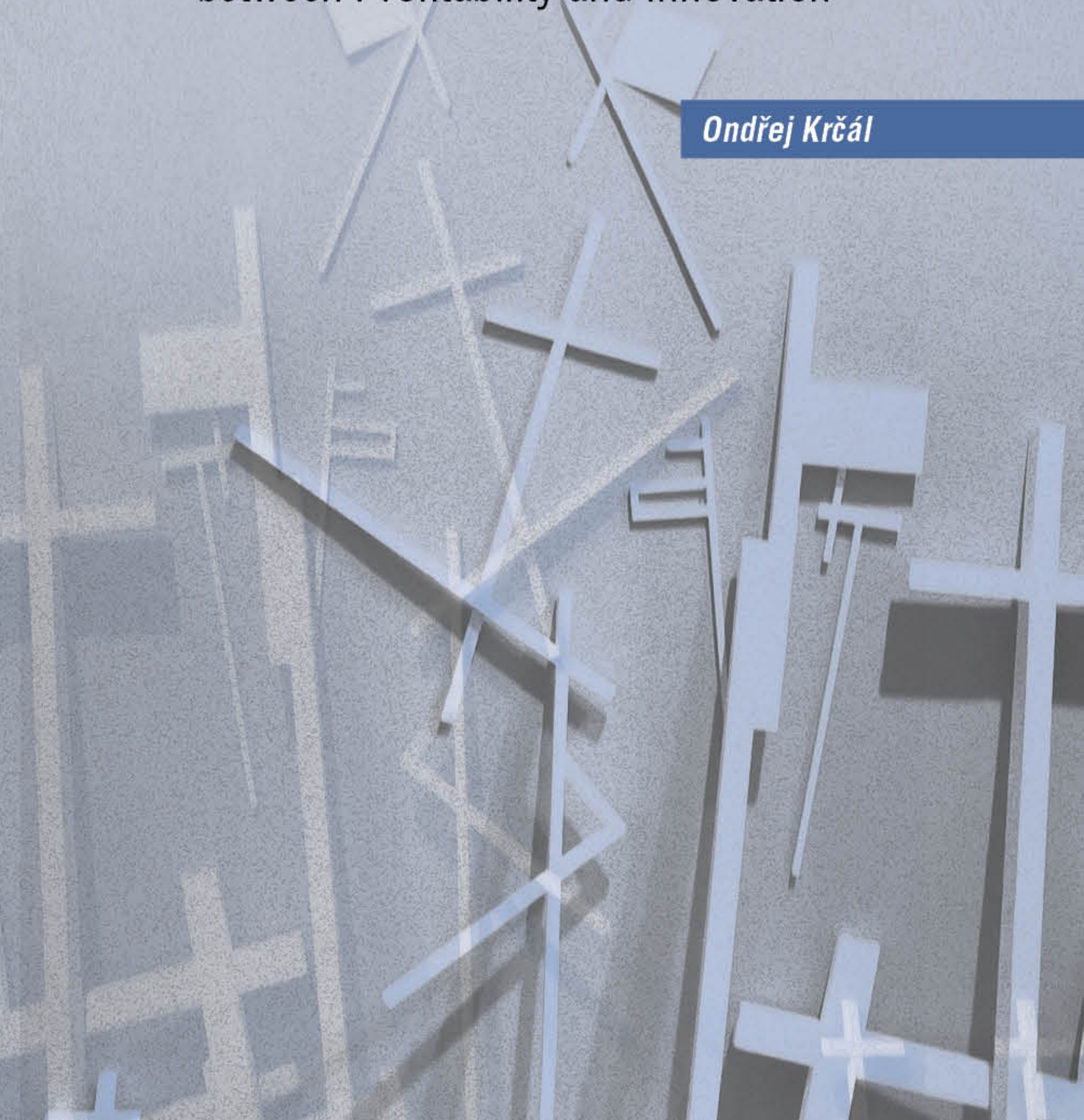
An Explanation of the Inverted-U Relationship between Profitability and Innovation

Ondřej Krčál



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Introduction

The literature on the relationship between competition and innovation has attracted the attention of the economic profession ever since the first publication of Schumpeter's *Capitalism, Socialism and Democracy* in 1942. In this work, Schumpeter argued that firms with market power might be more innovative than firms in competitive industries. Subsequently, many economists supported the Schumpeterian hypothesis that market power is good for innovation. Other important groups of economists argued that competition encourages innovation, or that innovation thrives at an intermediate level of competition.

The actual form of the relationship between innovation and competition, measured typically using profitability or concentration, is highly important for public policy, especially for competition policy, industrial policy and for the choice of the optimal intellectual property regime. For instance, if the Schumpeterian hypothesis is correct and competition reduces the innovative performance of firms, the goal of *competition policy* is unclear. By fostering competition, the authorities improve static efficiency because they reduce the dead-weight loss due to the market power of firms. But at the same time, they harm dynamic efficiency by reducing the innovative performance of firms. On the other hand, should market power discourage innovative activity, pro-competition policies would increase both the static and dynamic efficiency of markets. Similarly, if the goal of *industrial policy* is to create more innovative home industries, the optimal strategy also depends on the relationship between competition and innovation. Suppose that the Schumpeterian hypothesis is true and competition reduces innovation. Then it might be reasonable to use trade barriers to protect home industries from foreign competition. However, trade barriers will not be useful if competition stimulates innovation. Finally, the form of the relationship between competition and innovation is important for the choice of the optimal *intellectual property regime*. If Schumpeter's arguments are correct, a regime in which patents are assigned more easily and enforcement is stricter might be supported for two reasons. First, stronger patent protection increases the rents of the innovator and therefore the incentives to innovate. Second, stricter patent protection increases the market power of firms, which further enhances the innovative performance of the economy. On the other hand, if competition increases innovation, the possible positive effects due to stronger patent protection need to be weighed up against, among other factors, with the negative effects of less competitive environment on innovation.

Since Schumpeter's seminal discussion of the effect of market power on innovation, the relationship between competition and innovation has been widely studied in the empirical literature, mostly in the field of industrial organization, and the forces and effects behind the relationship have been discussed extensively in the theoretical literature. Unfortunately, neither the empirical nor the theoretical literature has provided clear support for the Schumpeterian hypothesis, or for the alternative hypothesis that competition encourages innovation. In the most influential recent contribution to the literature, Aghion *et al.* (2005) attempt to reconcile the opposing hypotheses. They find an inverted-U relationship between a profitability-based measure of competition and innovation and provide a natural explanation of the relationship that combines a positive and a negative effect of competition on innovation.

Following Aghion, Harris & Vickers (1997) and Aghion *et al.* (2001), Aghion *et al.* (2005) present a model of an economy consisting of a continuum of duopoly industries. Firms in these industries engage in step-by-step innovation. This means that a firm that has innovated moves exactly one technological step ahead, regardless of the technology used by the rival firm. Furthermore, the model sets the maximum possible difference between the technologies of the duopolists equal to one step. It means that firms one step ahead, called technological leaders, have no incentive to innovate. Hence the innovators are firms one technological step behind, called technological laggards, and firms at the same technological level, called neck-and-neck firms. The structure of product market competition is such that a rise in competition reduces innovation of laggard firms and increases innovation of neck-and-neck firms. The former effect of competition is called the *Schumpeterian effect* and the latter the *escape-competition effect*. The interplay of these two effects generates the inverted-U relationship between competition and innovation and two additional predictions, called Prediction B and Prediction C in this book. According to Prediction B, a rise in competition increases the share of unleveled industries with laggard and leader firms in the economy, which increases the average technological difference between the firms (called the *technology gap*). According to Prediction C, the peak of the inverted-U relationship is higher and occurs at higher levels of competition in an economy with a lower technology gap.

The predictions of the model of Aghion *et al.* (2005) have been tested in the recent empirical literature. While there is some support for the inverted-U relationship, the empirical evidence supporting the additional predictions is scarce. The lack of support for Prediction C is not so problematic because this prediction is not a necessary part of Aghion *et al.*'s explanation of the inverted-U relationship. On the other hand, Prediction B represents a necessary part of the explanation of the inverted U. According to this prediction, the proportion of neck-and-neck firms is relatively high in less competitive industries. Hence the escape-competition effect is likely to dominate the Schumpeterian effect, which means that a rise in competition increases the overall level of innovation. Conversely, the proportion of laggard and leader firms is relatively high in more competitive industries. In this case, the Schumpeterian effect is likely to dominate the escape-competition effect, which means that a rise in competition reduces innovation in the economy. The only two studies that find an inverted-U relationship between a profitability-based measure of competition and innovation and at the same time test for Prediction B are Aghion *et al.* (2005) and

Hashmi (2005). While the decreasing relationship between profitability and the technology gap found by Aghion *et al.* (2005) is consistent with their explanation, the flat and concave relationship in Hashmi (2005) is not compatible with Aghion *et al.*'s explanation of the inverted-U relationship. The empirical evidence, therefore, leaves room for an alternative explanation of the inverted-U relationship.

The goal of this book is to provide an alternative explanation of the inverted-U relationship between profitability and innovation that is able to reconcile the empirical findings of Aghion *et al.* (2005) and Hashmi (2005) related to Prediction B. More specifically, the book aims to provide realistically motivated models of the R&D decision-making of firms and test the predictions of the models using the empirical evidence of Aghion *et al.* (2005) and Hashmi (2005). The book should provide insights into possible causes of the relationship between the profitability of firms and innovation, which might prove useful for public policy.

In order to explain the empirical evidence, I introduce two models of innovation in this book: the basic model and the prospect-theory model of innovation. In the basic model, firms choose their R&D expenditures in order to maximize their expected profits within certain limitations. The aim of the model is to present a simple and general explanation of the empirical evidence. On the other hand, the prospect-theory model provides a more specific explanation, and predictions of the model correspond better to the empirical findings than predictions of the basic model. The prospect-theory model uses a behavioral theory of the decision-making process of managers. The R&D expenditures are chosen by managers of firms according to their preferences represented by the prospect-theory value function (Kahneman & Tversky 1979, Tversky & Kahneman 1992). Similarly to the model of Aghion *et al.* (2005), the size of innovation results from optimizing choices. On the other hand, the assumptions behind both models differ from Aghion *et al.*'s assumptions in several important aspects.

First, the model of Aghion *et al.* (2005) relates innovation to a theoretical measure of competition, which is shown to be increasing in the empirical profitability-based measure of competition (1−Lerner index). Thus their model is able to explain the empirical inverted-U relationship between profitability and innovation. The basic and prospect-theory models explain the empirical evidence directly by relating innovation to the profits of firms. This approach has two advantages. First, it avoids the problematic link between competition and profitability. As shown by Boone (2000, 2008), a rise in the level of competition may lead to both higher and lower industry profitability. Consequently, the predicted relationship between profitability and innovation might differ from the predicted relationship between competition and innovation. Second, it provides a more general explanation of the empirical evidence concerning the relationship between profitability and innovation because it covers all the possible factors responsible for variation in profitability, not only the intensity of competition like Aghion *et al.* (2005).

Second, the predictions of the model of Aghion *et al.* (2005) arise due to the assumption of step-by-step innovation and a specific structure of product market competition.

Thanks to these assumptions, competition has an opposite effect on innovation of laggard and neck-and-neck firms, which generates the inverted-U relationship and the related predictions. However, Aghion *et al.*'s explanation might not be valid in industries with a different mode of technological progress or different structure of product-market competition (see Subsection 1.3.2 for examples of such situations). In my explanation, all firms in an industry have the same incremental profit owing to innovation, which is either constant or decreasing in profits of firms. In this respect, my explanation is complementary to the explanation of Aghion *et al.* (2005). It is able to explain the empirical evidence even in the absence of either the Schumpeterian effect or both the Schumpeterian and escape-competition effects.

Third, there are important differences in the assumptions about the R&D process. In the model of Aghion *et al.* (2005), time is continuous. The intensity of innovative activity increases the probability that an innovation of a fixed size occurs at any moment in time. Furthermore, there are only two firms, which means that the innovative activity of one firm affects the optimal innovative effort of the other firm. On the other hand, time in my models is discrete. In each period, the R&D process generates an innovation with a certain probability. R&D expenditures influence the size of innovations. A rise in R&D expenditures increases the difference between the profits of the firm that succeeds or fails in generating an innovation. Finally, there are many firms in the industry, so that the size of R&D expenditures of one firm is assumed to have no effect on the innovative effort of other firms.

In this book, I provide several explanations of an inverted-U relationship between the profits and R&D expenditures of individual firms. The intuition behind all the explanations is similar. Starting at low levels of profits, a rise in profits tends to increase innovation because unprofitable firms, or their managers, are unable or unwilling to support high R&D expenditures. On the other hand, a rise in the profits of highly profitable firms reduces innovation because the benefits from an additional unit of R&D expenditure are decreasing in profits. The industry-level relationships between profits and R&D expenditures, called the *R&D function*, and profits and the technology gap, called the *technology-gap function*, depend on the distribution of profits in the industry. If all firms expect to earn similar profits, both R&D and technology-gap functions are likely to be inverse U- or V-shaped, which corresponds to the empirical findings of Hashmi (2005). On the other hand, if firms differ in profit earnings, the models are likely to predict an inverted-U or inverted-V R&D function and a decreasing technology-gap function, which corresponds to the findings of Aghion *et al.* (2005). In Aghion *et al.*'s model, Prediction B is a necessary component of the explanation of the inverted-U relationship. Hence the inverted-U relationship between competition and innovation emerges only if competition increases the technology gap in the industry. On the other hand, I provide a more flexible explanation of the inverted-U relationship between profits and innovation, in which the inverted-U R&D function is consistent with a concave or decreasing technology-gap function.

The rest of the book has the following structure: Chapter 1 presents a survey of literature related to the paper by Aghion *et al.* (2005). First, it presents the main assumptions and predictions of their model. Then it presents the recent empirical literature testing the predictions of their model, most importantly the empirical findings of Aghion *et al.* (2005) and Hashmi (2005). Finally, the chapter discusses the empirical evidence and some of the assumptions of the model of Aghion *et al.* and relates them to the alternative explanation presented in this book. Chapters 2 and 3 present the basic model and the prospect-theory model of innovation. Both chapters are organized in a similar way: they introduce the structure of the models first; then they present predictions of the models. More specifically: they relate firms' profits to their R&D expenditures; then they consider the relationship between profits and industry-level R&D expenditures; and finally they relate profits to the technology gap in the industry. Finally, both chapters show that for specific combinations of parameters, the predictions of the models correspond to the findings of Aghion *et al.* (2005) and Hashmi (2005). Chapter 4 discusses the robustness of the predictions to a variation in parameters. And finally, the last chapter sets down the conclusion.

Chapter 1

Survey of literature

The modern literature on the relationship between competition and innovation starts with a provocative thesis by Joseph Schumpeter. Schumpeter challenges the view that competition is beneficial for consumers. He argues that in the long run, the static inefficiency of monopolistic industries might be more than offset by their better innovative performance. He presents two arguments in favor of this thesis. First, firms with market power might have access to superior methods or better inputs because of better financial standing or uniqueness. “There are superior methods available to the monopolist which either are not available at all to a crowd of competitors or are not available to them so readily: ... for instance because monopolization may increase the sphere of influence of better, and decrease the sphere of influence of the inferior, brains, or because the monopoly enjoys a disproportionately higher financial standing.” (Schumpeter, 1994 [1942], pp. 100–101) Second, he argues that monopolistic practices or a better financial standing might mitigate the negative consequences connected to uncertain innovative activities. Therefore, monopolies might be bolder innovators than competitive firms. Or as Schumpeter explains, “[t]here is no more of paradox in this than there is in saying that motorcars are traveling faster than they otherwise would because they are provided with brakes.” (Schumpeter, 1994 [1942], pp. 88–89)

From the beginning of the discussion, the Schumpeterian hypothesis in favor of market power finds support among many economists. Other economists present arguments and empirical evidence in favor of a positive effect of competition on innovation. The following list of important contributions shows that the discussion continues to the present day. The notable theoretical arguments for a positive or a negative relationship between competition and innovation are put forward by Fellner (1951), Arrow (1962), Scherer (1967b), Loury (1979), Lee & Wilde (1980), Dasgupta & Stiglitz (1980), Reinganum (1982), Vickers (1986), and Aghion & Howitt (1992). For studies reporting a negative relationship between competition and innovation that are consistent with the Schumpeterian hypothesis, see e.g. Phillips (1956), Horowitz (1962), Phillips (1966), Scherer (1967a), Greer & Rhoades (1976), Kraft (1989), Tinkvall & Poldahl (2006), Artés (2009), Hashmi & Van Biesebroeck (2010), and Hashmi (2012). For studies finding a positive effect of competition on innovation, see e.g. Maclaurin (1954), Weiss (1963), Allen (1969), Adams (1970), Johannisson & Lindström (1971), Acs & Audretsch (1988), Geroski (1990), MacDonald (1994), Nickell (1996), Blundell, Griffith & Van Reenen (1999), Djankov & Murrell (2002), Okada (2005), Griffith, Harrison & Simpson (2006), Gorodnichenko, Svejnar & Terrel (2008), Bloom, Draca & Van Reenen (2011), Correa & Ornaghi (2011), Berubé, Duhamel & Ershov (2012).

A third important hypothesis is introduced to the discussion more than two decades after Schumpeter's seminal work. According to this hypothesis, the relationship between competition and innovation is first increasing and then decreasing in competition, forming an inverted-U relationship. The intriguing aspect of the inverted-U hypothesis is that it might potentially reconcile the empirical findings of positive and negative relationships between competition and innovation. Furthermore, it might explain the relationship using theoretical arguments for both a positive and a negative relationship – the positive effect of competition dominating the negative effect if competition is low, and vice-versa if competition is high. Theoretical explanations of the inverted-U relationship are presented by Scherer (1967a, 1967b), Kamien & Schwartz (1972, 1976), Nohria & Gulati (1996, 1997), Schmidt (1997), Mukuyama (2003), Aghion *et al.* (2005), Lee (2005), and Vives (2008). Some empirical support for the inverted-U hypothesis is provided by Williamson (1965), Comanor (1967), Scherer (1967a), Scott (1984), Levin, Cohen & Mowery (1985), Schaffner & Seabright (2004), Aghion *et al.* (2005), Kilponen & Santavirta (2005), Hashmi (2005), Tingvall & Poldahl (2006), Tingvall & Karpaty (2008), Askenazy, Cahn & Irac (2008), Wiel (2010), Alder (2010), Polder & Veldhuizen (2012), and Peneder & Wörter (2012).

The aim of this book is related directly to the seminal model of Aghion *et al.* (2005), which provides an explanation of the inverted-U relationship between competition and innovation and two additional testable predictions. For this reason, the discussion in this section is limited exclusively to the theoretical model of Aghion *et al.* (2005) and the related empirical literature. This limitation is justified by the fact that there are many excellent surveys of the literature on the relationship between competition and innovation (for the most important ones, see Kamien & Schwarz 1975, Cohen & Levin 1989, Scherer 1992, Cayseele 1998, Ahn 2002, Gilbert 2006, and for a specialized survey of the early literature on the inverted-U relationship, see Krčál 2010c). It is therefore not necessary to provide a comprehensive survey of the entire literature on the relationship between competition and innovation.

This chapter consists of three parts. Section 1.1 introduces the model of Aghion *et al.* (2005). It presents the main assumptions of their model and introduces three predictions relating competition, innovation and the technology gap in the industry. Section 1.2 reviews the recent studies testing predictions of the model of Aghion *et al.* (2005). The studies provide some evidence of the inverted-U relationship between competition and innovation and limited evidence supporting the additional predictions. Section 1.3 summarizes the main findings of the chapter and discusses the correspondence of the findings to predictions of the model. Furthermore, it discusses some of the assumptions of Aghion *et al.*'s model and relates them to the assumptions of my explanation presented in the subsequent chapters.

1.1 A review of Aghion *et al.*'s model

Aghion *et al.* (2005) present a general-equilibrium model that builds on the previous work of Aghion & Howitt (1992), Aghion, Harris & Vickers (1997), and Aghion *et al.* (2001). Their model economy consists of a continuum of duopoly sectors in which the duopolists have constant marginal costs. They engage in step-by-step innovation, which means that innovation on the part of each firm improves its technology by one step. This is equivalent to a reduction of marginal costs by $1/\gamma$, where the parameter $\gamma > 1$ measures the size of innovation. Furthermore, the nature of the technology is such that the difference between the levels of technological development of firms cannot exceed one step. For this reason, there are only two types of industry in the economy: *leveled industries* containing *neck-and-neck firms* that have the same marginal costs; and *unleveled industries* in which one firm (called the *leader*) is one technological step ahead of the other firm (called the *laggard*).

Because of the limitation on the technology difference between the duopolists, leaders have no incentive to innovate. Hence the potential innovators consist of the remaining neck-and-neck and laggard firms. By spending a certain amount of labor, a neck-and-neck or a laggard firm innovates with a Poisson hazard rate of n_0 or n_{-1}, respectively. Furthermore, a laggard firm may imitate the leader's technology with an exogenously determined Poisson hazard rate h (called the *imitation rate*). Hence the probability that a laggard firm moves one step ahead at any moment in time is $n_{-1} + h$. The duopolists engage in Bertrand competition with homogeneous products. Product market competition is parameterized as a level of collusion that affects only the profits of neck-and-neck firms. At the highest end of the competition range, there is no collusion and neck-and-neck firms earn zero profit. As the level of collusion increases, the profits of neck-and-neck firms increase. There is no collusion in unleveled industries. Therefore, laggard firms earn zero profits and the profits of leaders depend on the size of innovation γ.

A rise in product market competition Δ (a reduction of the level of collusion) has two effects on innovation. According to the *escape-competition effect*, competition increases innovation on the part of neck-and-neck firms. The intuition behind the effect is straightforward. A rise in competition reduces the profits of neck-and-neck firms, but has no effect on the profits of leaders. Hence competition increases the incremental profits from innovation (called the reward) of neck-and-neck firms. Consequently, competition increases the probability that a neck-and-neck firm innovates at any moment in time n_0. According to the *Schumpeterian effect*, competition reduces innovation on the part of laggard firms. This effect arises because competition lowers the profits of neck-and-neck firms, but has no effect on the profits of laggard firms. Hence a rise in competition reduces the reward of laggard firms, and therefore lowers the probability that a laggard firm innovates at any moment n_{-1}.

In steady state, the proportion of leveled and unleveled industries adjusts so that the probability that an industry becomes leveled equals the probability that an industry becomes unleveled. Hence the escape-competition and Schumpeterian effects influence the steady-state proportion of leveled and unleveled sectors in the economy, and consequently the overall innovative performance of the economy. This process generates the following three predictions:

- **Prediction A:** For certain values of parameters, the relationship between competition and the overall level of innovation in the economy has an inverted U-shape (see Proposition 2, Aghion *et al.* 2005, p. 715).

- **Prediction B:** A rise in competition increases the expected technology gap measured as the proportion of unleveled industries in the economy (see Proposition 4, Aghion *et al.* 2005, p. 717). Prediction B is also called the *composition effect*.

- **Prediction C:** The peak of the inverted-U relationship is higher and occurs at higher levels of competition in an economy with a higher proportion of leveled industries (see Proposition 5, Aghion *et al.* 2005, p. 717).

First, I explain how the escape-competition and Schumpeterian effects influence the proportion of unleveled sectors in the economy (Prediction B) and the overall innovative performance of the economy (Prediction A). Then I explain what is the relationship between the technology gap and the overall innovative performance (Prediction C).

Consider the situation of the model economy under a high, low and intermediate level of competition. If competition is high, neck-and-neck firms are highly innovative while the innovation of laggards is low. It means that while neck-and-neck firms need relatively little time to innovate and shift an industry to the unleveled state, laggards need relatively more time to innovate, so that the industry stays in the unleveled state relatively longer. Therefore, the steady-state proportion of unleveled industries among highly competitive industries is relatively high. Since innovative performance of highly competitive *unleveled* industries is low due to the Schumpeterian effect, the overall level of innovation in highly competitive industries is relatively low. On the other hand, if competition is low, laggard firms are highly innovative and neck-and-neck firms are slow to innovate. The industries need relatively less time to move from the unleveled to the leveled state, than vice-versa. Therefore, the steady-state proportion of leveled industries is relatively high. Since neck-and-neck firms under low competition are less innovative due to the escape-competition effect, the overall level of innovation will be relatively low. Finally, if the level of competition is intermediate, both laggard and neck-and-neck firms need intermediate time to innovate. The proportion of leveled and unleveled industries in the economy is also intermediate. Therefore, the level of innovation in the economy might be higher than under low or high competition.

This provides an intuitive explanation of Prediction B. More competition increases innovation of neck-and-neck firms and reduces innovation of laggard firms. Hence it increases the proportion of unleveled sectors, i.e. the expected technology gap, in the economy. The previous paragraph also explains the intuition behind Prediction A. If competition is high or low, a relatively high share of industries needs a relatively long time to innovate. If competition is intermediate, all industries need intermediate time to innovate. Therefore,