T.C.
YILDIZ TEKNİK ÜNİVERSİTESİ
SOSYAL BİLİMLER ENSTİTÜSÜ
İKTİSAT ANA BİLİM DALI
İNGİLİZCE İKTİSAT PROGRAMI

YÜKSEK LİSANS TEZİ

INNOVATION OR IMITATION: A PATENT RACE APPROACH

Nurten KAYNARCA
16729001

TEZ DANIŞMANI
Doç. Dr. Burak ÜNVEREN

İSTANBUL
2019

T.C.
YILDIZ TEKNİK ÜNİVERSİTESİ
SOSYAL BİLİMLER ENSTİTÜSÜ
İKTİSAT ANA BİLİM DALI
İNGİLİZCE İKTİSAT PROGRAMI

YÜKSEK LİSANS TEZİ

INNOVATION OR IMITATION: A PATENT RACE APPROACH

Nurten KAYNARCA
16729001

TEZ DANIŞMANI
Doç. Dr. Burak ÜNVEREN

İSTANBUL
2019

T.C.
YILDIZ TEKNİK ÜNİVERSİTESİ
SOSYAL BİLİMLER ENSTİTÜSÜ
İKTİSAT ANA BİLİM DALI
İNGİLİZCE İKTİSAT PROGRAMI

YÜKSEK LİSANS TEZİ

INNOVATION OR IMITATION: A PATENT RACE APPROACH

Nurten KAYNARCA
16729001

Tezin Enstitüye Verildiği Tarih: 22.04.2019
Tezin Savunulduğu Tarih: 29.05.2019
Tez Oy Birliği ile Başarılı Bulunmuştur

	Unvan Ad Soyad	İmza
Tez Danışmanı	**: Doç. Dr. Burak ÜNVEREN**	
Jüri Üyeleri	**: Prof. Dr. E. Ünal ZENGİNOBUZ**	
	Prof. Dr. Murat Donduran	

İSTANBUL
MAYIS 2019

CONTENTS

TABLE LIST

FIGURE LIST

ABBREVIATION

CNY	: Chinese Yuan
FDI	: Foreign Direct Investment
GII	: Global Innovation Index
IPR	: Intellectual Property Right
PIPR	: Private Intellectual Property Rights
PRC	: People's Republic of China
R&D	: Research and Development
SME	: Small and Medium Sized Enterprises
TIP	: Technological Innovation Plan
TRIPS	: Trade-related Intellectual Property Rights
USD	: United States Dollar

ABSTRACT

INNOVATION OR IMITATION: A PATENT RACE APPROACH
Nurten KAYNARCA
April, 2019

Innovation and imitation of technology are intensively discussed in the literature of economic development. In spite of many empirical and theoretical findings revealing the importance of innovation for rapid economic development, the developing economies are still behind developed economies in terms of R&D expenditure and its share in GDP. Hence, the reason behind differential levels of development among countries cannot be just be the limited resources in the lagging countries as compared to developed countries.

Therefore, understanding the motivation of firms to make R&D expenditure for innovation is crucial. Patent race models are important contributions to the literature in this direction. Patent races are multi agent-based models that discusse the R&D investments of firms to obtain patent protection for a specific technology. In our model, we pursue a patent race approach to the technological gap between incumbent and entrant firms as well as innovation and imitation decisions of entrant firms. The return of successful innovation and the probability of early success are differentiated for incumbent and entrant firms. The model is calibrated by the mobile phone sector data. The calibration suggests that there is a subtantial gap between the probabilities of early success of incumbents and entrants and. Moreover, staying out of patent races (imitation) is more profitable for an entrant firm at the calibrated parameter levels.

Key Words: Market Structure, Patent Race, Innovation, Imitation.

ÖZ

İNOVASYON YA DA İMİTASYON: PATENT YARIŞLARI YAKLAŞIMI
Nurten KAYNARCA
Nisan, 2019

İktisadi kalkınma literatüründe firmaların inovasyon ve imitasyon kararları yoğun biçimde tartışılmıştır. Hızlı ekonomik kalkınma için teknolojik inovasyonun önemini ortaya koyan birçok ampirik ve teorik bulguya rağmen, gelişmekte olan ekonomilerin Ar-Ge harcamalarının GSYH'nın içindeki payı, gelişmiş ülke ekonomilerinin çok gerisindedir. Bu durumdan da anlaşılacağı üzere, gelişmiş ve gelişmekte olan ülkeler arasındaki teknoloji açığının arkasındaki sebep yalnızca gelişmekte olan ülkelerin, gelişmiş ülkelere kıyasla sınırlı kaynaklara sahip olmaları olamaz.
Bu noktada, firmaların inovasyon amacıyla yaptıkları Ar-Ge yatırımlarını iyi anlamak ve analiz etmek gerekmektedir. Patent yarışı modelleri bu doğrultuda literatüre önemli katkı sağlamıştır. Patent yarışları, belirli bir teknoloji için patent koruması elde etmek amacıyla firmaların Ar-Ge süreçlerini gösteren çoklu ajan tabanlı modellerdir. Oluşturduğumuz modelde halihazırda piyasada bulunan ve piyasaya yeni katılan firmalar arasındaki teknolojik açık ve yeni firmaların inovasyon ve imitasyon karar süreçleri, patent yarışları yaklaşımı ile incelenmiştir. Daha önce çalışılmış patent yarışları modellerinden farklı olarak, inovayonun geri dönüşü ve başarılı inovasyonu ilk önce yapma ihtimali içerdeki firmalar ile yeni firmalar için farklılaştırılmıştır. Model, cep telefonu sektörü verileri ile kalibre edilmiştir. Kalibrasyon ile halihazırda piyasada bulunan ve piyasaya yeni katılan firmaların erken başarı ihtimalleri arasında büyük bir fark olduğu ve yeni firmalar için patent yarışlarının dışında kalmanın yani imitasyon yapmanın daha rasyonel bir karar olduğu çıkarımı yapılmıştır.

Anahtar Kelimeler: Piyasa Yapısı, Patent Yarışları, İnovasyon, İmitasyon.

ACKNOWLEDGMENTS

First and most of all, I would like to thank to my advisor Doç. Dr. Burak Ünveren for the valuable guidance, advice and support with patience from the beginning of this study. I would like to thank to my family for their valuable feedback and support. Without their support and encouragements, I could not complete this study. I would like to extend my sincere gratitude to Prof. Dr. Göksel Aşan for his support and understanding in this process. I am also thankful to Murat Ali Çengelci for his valuable advice and constructive criticism.

İstanbul; April, 2019 Nurten KAYNARCA

TABLE LIST

FIGURE LIST

1. INTRODUCTION

In this thesis, we focus on the effects of patents races on technological innovation. It is widely accepted that technological progress is the only viable method of perpetual growth of GDP per capita. Economic growth and development literature, however, have evolved over time until reaching this concensus. Indeed early growth models highlighted the importance of production factors (e.g. capital and labor) that are accepted as endogenous, but they ignored technology by considering it as an exogenous variable. Romer (1986) and Lucas (1988) introduce the growth models where technology is endogenous. Endogenous growth models provide us wider perspective to understand the gap between countries in terms of technology and aggregate economy.

Our study is also concerned with understanding the reasons of the technological gap between firms based on patent race modelling. Patent races are multi agent-based models that shows the R&D processes of firms to obtain patent protection for a specific technology. Initial patent race models assumed symmetric firms. Later, the case of asymmetric firm sizes was introduced to analyze the behaviors of monopolies and new firms that are willingness to enter market by innovation. Our thesis is based on the assumption that initial market structure is a duopoly and both firms are technological leaders. The main focus of our model is to understand the decision process of a third firm. This potentail entrant decides whether to enter in the patent race or to stay out to imitate the obselete technologies. Tirole (1994), Reinganum (1989), Gilbert and Newberry (1984) are the closest studies to our model in terms of asymmetric patent races. In comparison to those studies, we consider the effect of initial competition between incumbent firms and imitation on the return of successful innovation.

Imitation and innovation are discussed in literature intensively in terms of economic growth. Mukoyama (2003) constructed a model that industry leaders engage in R&D for innovation while outsiders engage in R&D for imitation. It is assumed that imitation is the only way to enter industry for a new firm. By the help of patent race models, we calculate the expected value of imitation by linking the probability of imitation to the probability of leader firms' successful innovation. Hence, imitation decision of a new firm depends on patent race between technological leaders since a successful innovation makes existing technology of leaders more affordable for a new firm.

In addition, we discuss economic policy proposals to close the technological gap between countries and firms. In this direction, we observed that many studies highlight the importance of government interventions in direct or indirect ways. R&D subsidy is one of the direct ways of promoting firms to invest in R&D. However, government should set a right framework of this subsidies by considering inequalities between firms and market dynamism. As Laincz (2009) states, in some cases wrong R&D subsidy policies can cause the persistency in market leadership and lack of competiton.

In the rest of paper, we focus on the literature on economic growth and innovation as a market determinant and development tool. Later, the benchmark of patent race models and the trade-off between innovation and imitation will be analzyed. Then we move to our model. We construct two different patent race models with Cournot and Bertrand competition structures. In the last section, plausible economic policies to promote development through innovation will be discussed.

2. LITERATURE REVIEW

2.1. Innovation and Market Structure

In this section, we will discuss the mutual interaction between innovation and market structure. Both are important factors in economic growth. Markets determine the return of innovation and incentives of economic agents to innovate. Innovation does not affect only the innovator, but it also affects the other players in the market.

A crucial notion that provides market power to firms with technological advantage is the patent system. Patents are grants that provide a property right and commercial monopoly power to inventors of a new product or production methods. Patent protection is valid for a time period determined by legal authoruties. After patent protection of an invention expires, other individuals and firms are free to produce and sell this invention. Early studies on innovation have focused on patent protection to make inferences about incentives to innovate and markets structure before and after innovation. Phillips (1966), states that adjusting of patent rights of existing firms to reduce entry barriers and a less concentrated market cause lower prices and output. In addition, he suspected that if technological progress does not create scale economies due to the size of capital expenditures or the amount of learning involved in their use, a competitive structure may persist with technological change over long periods of time. Cayseele (1998) summarized the studies from 1975 to his time, providing us a general look on the relationship between innovation and market structure. Cayseele argues that since Philips (1966), economics advocated the idea that if there is causality from market structure to innovation, we have many reasons to believe that innovation affects market structure in same way.

In later studies, multi agent-based models was introduced to analyze the process of R&D to obtain patent protection and market structure before and after innovation. These models are called as patent race. It is a game theoretical approach to competition between firms that invest in R&D to obtain patent protection. Patent protection provide a future market power that enables firms to obtain high profits and to sustain innovative activities. For this reason, it is a necessity to develop better understanding on market structure and competition before and after patent protection.

Loury (1979), Dasgupta and Stiglitz (1980), and Reinganum (1989) constructed memoryless patent race models that are independent of initial market structure. In these models, firms are interested in new product or production method. Innovation is stochastic process where a successful invention ends the game. Reinganum (1989) points out that stochastic innovation processes cause the circulation in technological leadership while deterministic innovation lead to a single persistent technological leader in industries. In these models, every firm have one decision variable; investment level on R&D. To be successful and obtain market power, they increase investments slightly to guarantee earlier innovation. The investment strategies in later dates are dependent on earlier investment levels of rival firms.

Dasgupta and Stiglitz (1980) states that, since each firm decide its actions in a certain time simultaneously, it is assumed that in Nash equilibrium, each firm believes that the actions of the other firms will be unchanged as a result of its own action. The model is constructed by assuming, many firms enter patent race with same R&D function. Their most remarkable implication that is discussed strongly, is that although there is competition in R&D activities for every kind of firms, there are strong tendencies for a monopolized industry to remain monopoly.

Furthermore, since firms increase their investment until cost of innovation exceeds return of innovation, firms' limits to increase investment is determinant factor in innovation success. Gilbert and Newberry (1984) studied the behavior of monopolies to prevent market entry. They stated that potential competitors choose to stay out of patent race because they know monopolies behave rational and they accelerate their research in case of competitors enters the patent race. In the same context, Futia (1980) develops a patent race model that the introduction of new product or new production methods leads to changes in industry structure to theoretically discuss the relationship between market concentration and innovation process. Futia (1980) finds that long run pace of innovation is higher in a blockaded market with higher concentration.

Gottschalk & Janz (2001) empirically studies the effect of R&D on market concentration. They conclude that innovative activities positively affect sales concentration in the long run. On the other hand, firms choose to innovate to avoid competition pressure in less concentrated markets. In industries that is less competitive, market structure does not stay the same because of entrants which will feed the competition and innovation

The reasons behind this inference is that firms in a more concentrated market have better access to resources to finance R&D process and those firms may offset the investment with return of innovation easily. In a recent study, Aghion and Bircan (2017) analyze the effect of innovation on market structure by considering the leaders and follower in markets. They conclude that competition affects innovation negatively in industries with few technological leaders and many followers. They also propose an economic policy that state governments must be more protectionist in those industries to eliminate the negative effect of international competition.

In one of the most influential studies in innovation, Arrow (1962) analyzes the firms' incentive to innovate and the effect of initial market structure on innovation. In particular, Arrow (1962) computes the level of increase in profits of a firm that has highest technology in the market. He conlcudes that obtaining the highest technology, interpreted as innovation, increases profits of competitive firms more than a monopoly. The reason behind this conclusion is that a monopoly would already earn excess profit and would not experience large increases with innovation in comparison to competitive firms. Moreover, Arrow finds that society attaches value on innovation even more than competitive firms as long as prices are equal to marginal cost. He introduced the "replacement effect" implying that potential entrants invest in R&D for radical innovations, while incumbents target incremental innovations that improve existing technology with R&D. Hence, he supposed that competitive markets are more innovative than monopolistic markets where firms are less willing to invest adoption of new technologies.

In this direction, Mazzucato (2000) states that small enterprises are more able to become market leaders in industries with very fast rates of cost reduction by innovation. If cost reduction with innovated technology is very slow, then market tends to be more concentrated. Shefer and Frenkel (2005) study the relationship between investment in R&D and firm size empirically. Their findings are consistent with Mazzucato (2000). They find that the share of labor engaged in R&D and the rate of investment in R&D are closely and negatively related to the firm size.

Based on the replacement effect, Acemoğlu & Cao (2010), developed a Schumpeterian endogenous growth model that decomposes US industry-level productivity growth that is accounted for by existing firms and continuing establishments. They pointed out that Arrow's replacement effect is consistent with qualitative and quantitative evidence on the nature of innovation. Rosen (1991) also built a model stating that the relationship between market position and R&D strategy depends on how the innovated technology interacts with initial technology level of firms.

Furthermore, Rosen (1991) assumed that firms have two choice variables; R&D projects and level of investment as different from earlier patent race models. R&D project as choice variable indicates that firms not only decide R&D investment level but also consider risk return of innovation. In this regard, bring criticism to Reinganum (1989) and other economists in terms of investment as a sole factor determining success probabilities. He indicated that the risk-return tradeoff is crucial to the balance between market position and R&D investment. This model emphasized that large firms invest more as expected but they prefer R&D projects that cause small increments to their existing technologies. In this regard, small firms can exist in new markets with major innovations by not investing more than larger firms due to differences in R&D project selection.

One of the recent empirical analysis on the relationship between innovation and market structure belongs to Buddelmeyer et. al. (2006) that focus on firm survival by categorization of innovation investment and capital. They conduct their analysis with an unbalanced panel data over 290,000 Australian companies. The results suggest that there is a positive relationship between firm survival and past successful innovations of firms. Firms that have patents which are worth renewing also have the required financial, management and economic capabilities to increase their survival chance. These results are important to understand why technological intensive markets have tendencies to imperfect competition.

Until now, we discussed the evolution of growth theories on the basis of technology and the mutual interaction between innovation and market structure. Our study will be based on patent race models that will be discussed withdetails in the next sections. But now we will focus on the effect of imitation on innovation considering differences in development levels of countries and technological diffusion through FDI.

2.2. Imitation and Innovation

The main object of this section is to study the interrelationship between innovation and imitation by considering comples economic relations between different types of countries. Especially, the trade-off between innovation and imitation is important for developing countries that are in the verge of high-income levels. While imitation is less risky and also profitable at a certain level, innovation processes are riskier and provides more profits that make economies jump to higher income levels.

Economic growth can be achieved through both innovation and imitation. However, there is a complex interrelationship between those two choices. Economic policies to promote development through innovation and imitation, are extensively studied in the literature but there is still not an agreement about the effect of imitation on development. In particular, there are two opposing views about the effect of imitation on economic growth and innovative activities. Some studies show that imitation and higher competition reduce incentives to innovate in markets. Technological innovators make R&D investments for monopoly profit. That is why, imitation discourage innovative firms and reduce aggregate innovation level. On the other hand, the idea that imitation causes knowledge diffusion and provides a basis for new technological innovations, is also supported widely. Newly established firms start to operate in market by imitating and then start to make R&D investments for innovation. As stated in Freeman and Soete (1997), Toyota started production by learning from Ford production systems and became one of the most efficient firms in automobile industry. Mukoyama (2003) showed that potential entrant firms engage in R&D for imitation, even if they cannot obtain any profit. They learn from imitation to make R&D investment for next inventions. Thus, imitation may affect innovation positively by increasing the number of innovative firms.

Some studies explained the effect of imitation by the asymmetry in development levels of countries and the interaction between their economies. In many studies on this subject (e.g. Grosman and Helpman, 1991b), countries are categorized in two groups as Northern and Southern countries. Northern countries can be thought as the resource of technological innovation. Southern countries are poorer and have limited resources to make innovation.

For southern countries, FDI is another way to reach new technologies and knowledge accumulation as a basis of innovation. FDI is not just provide a financial resource but also technology and knowledge for host country. While imitation requires some level of R&D investment, FDI provide direct technological spillover to domestic firms in southern countries. However, the quality level of technology transferred through FDI and its effect on innovation and imitation is one of the most debated subjects of economics. Some studies indicate that multinational firms transfer older technologies to host countries due to the possibility of future competition of local firms. In addition to this strategic behavior, another reason can be the low absorptive capacity of host country for state-of-the-art technology. If technological gap is huge between developed and developing countries, then domestic firms cannot host high quality FDI.

Glass and Saggi (1998) associated the quality level of technology transfer between Northern and Southern countries to the technology gap between those countries. They stated that technology gap is determined by local R&D (imitation) in developing countries and R&D (innovation) in developed countries. They discuss about economic policies to promote high quality FDI by closing technological gap through imitation. The model is appropriate for a developing economy that have insufficient level of technology to host state-of-the-art FDI. A Southern country must have sufficient human capital and business environment with appropriate institutional structure to encourage high quality FDI. For this kind of economies, technological progress can be achieved by encouraging local R&D (imitation) or discouraging low quality FDI. Imitation reduces technology gap between Northern and Southern countries by increasing knowledge level of imitating firms. If southern countries allow to northern firms to produce low quality technologies in domestic market, that discourage imitation by indigenous firms.

Grossman and Helpman (1991b) distinguished firms as leaders that successfully developed new innovated products, and followers that are behind the leaders with older generation of the products. They stated that a Northern firm earns profits until a Southern firm imitates its new generation products. This imitation provides profit flow to southern firms (followers) until another innovation occurs. They find two equilibrium levels for "inefficient followers" and "efficient followers". In the case of inefficient followers, Northern leader firms have productivity advantage over potential entrants. Leader firms engage in R&D whenever Southern firms imitate their current products. When the productivity gap between technological leader firms and potential entrant firms is sufficiently small, new entries to the industry is more possible. As followers become more efficient, the Northern firms prefer to innovate substantially more advanced products than the ones copied by the South.

Glass & Wu (2007) focus on IPR (intellectual property rights) policies that have significant effect on innovation and imitation level in both Northern and Southern countries. When innovation includes new products or production methods, stronger IPR protection leads more FDI and innovation in Southern countries. However, when innovation brings higher quality levels, stronger Southern IPR protection can reduce FDI and innovation. When Southern countries have weaker IPR protection, Northern multinationals prefer to keep production in North, due to higher risk of imitation.

Segerstrom (1991) builds an economic growth model according to which firms can enter both innovation and imitation races, considering the effect of government subsidies. He finds out that once-and-for-all increase in the government subsidies to innovation affects imitative R&D intensity positively. Likewise, once-and-for-all exogenous increase in government subsidy to imitation increases innovative R&D intensity. These findings are grounded on the assumption that cheaper innovation causes shorter expected time to be leader firms with innovated technology and this spurs imitative activities.

In our study, we will approach to trade-off between imitation and innovation for firms by looking at patent race models which give us a perspective on the return of R&D investments. Our argument is a firm can benefit from a patent race even if the firm did not enter the patent race by imitation. The return of imitation depends on patent race between technological leader firms. New firms make choices about R&D investments on innovation by considering the return of imitation. We considered the case that new inventions do not extinguish older technologies so some firms can continue to operate with these older technologies with positive profits. Before moving to our model, it is important to understand benchmark of patent race models, which we discuss next.

2.3. Innovation and Economic Growth

In this chapter we shall discuss the evolution of and the interaction between the theories of economic growth. This enables us to grasp the contribution of the present output/capital ratio and growth rates. In this way, Swan's diagram is more useful to illustrate the variations of technical progress. Today's growth theories are grounded on Solow-Swan model that postulates an aggregate production function linking output to capital and augmented labor. This production function exhibits constant returns to scale that indicate increasing capital and labor causes to increase output by same amount. In this model, the growth rate of labor is assume to be constant. Capital is, however, accumulated by saving a constant rate of total production. Under these conditions, the most key finding of Solow-Swan model is that growth rate of income per capita is equal to growth rate of technology. Another implication of this model is the convergence among countries in terms of their income levels. We will again touch on this subject shortly.

One lack of Solow-Swan model is the assumption that savings are a constant fraction of national income. In the work of Frank Ramsey (1928), which is interestingly older than Solow-Swan model, the saving rates are endogenous and determined by decisions of rational individuals. In this model, households are both consumers and producers; and they choose their optimal consumption and investment levels in order to maximize their utility. Ramsey (1928) specifies a utility and production function with finite number of agents and infinite time horizon. All agents are assumed to be alike and the model is constructed as a reperesentative agent model to make aggregation simplier. Three active markets are considered in the model: First market is for output good. Second and third one is for labor and capital services. There is perfect competition in all markets. The competitive equilibrium levels in these markets are ofsett by maximization of a representative household utility and firm profits. Endogenous consumption and investment assumption has made the growth theories more realistic to understand the growth patterns through individual agents' decisions (Indeed, the original formulation of Ramsey postulates a benelovent central planner who maximizes the life-time utility subject to feasibility constraints without any role played by the markets. The decenrtralized modern interpretation of this model is perfect competition in all markets. This interpretation is due to the first fundamental theorem of welfare). Grossman and Helpman (1991) stated that an economy with constant returns to scale in capital, labor and constant stock of labor and investment, cannot sustain economic growth through technological progress because of fall in marginal product of capital. In economies with optimal saving, however, if marginal product of capital is bounded below, economic growth can be sustained in the absence of technological progress.

Until now, we focused on growth models that technology is accepted as exogeneous. However, technological development is a result of decisions taken by individuals and firms. In this context, Romer (1986) and Lucas (1988) brought endogenous technological progress to the literature of economic growth. They aimed to understand why technological progress differs from country to country by analyzing the behavior of economic agents and economic policy of the government. Lucas (1988) asked if there is any government policy that can boost the growth performance of the economy. If so, what is this policy and if not, what is the nature of the country that makes growth boosting policies impossible? Lucas introduced the variable of human capital to measure productivity of labor and to underline the importance of technological progress on economic growth. According to this model, schooling and learning by doing are the main determinants of human capital. Human capital formation causes endogenous growth with non-decreasing marginal returns. Lucas (1988) defined two extra variables; first notates the proportion of total labor time spent working, and second one is for stock of human capital. The AK production function is written with those variables and in per capita terms with constant returns to scale. He defined a differential equation for human capital accumulation as well as a usual differential equation for capital accumulation. Another endogenous growth model by Romer (1986) is very similar to that of Lucas (1988). His model was a long-run growth analysis with endogenous technological change. Knowledge accumulation by forward looking agents determines the technology level. He introduced the notion of research for leading to knowledge accumulation and providing profits from inventions. He defined a steady state growth rate that is chosen by social planner and assumed the social planners considers some externalities that are ignored by individuals in decision proceses. It is argued that growth rates of countries do not converge as claimed by Solow-Swan model. Lucas, Romer and other endogenous growth theorist accept technology and human capital as main and complementary factors of economic growth.

Economic growth literature has come to new dimension with the introduction of endogenous growth theories of Lucas and Romer. Recent papers have focused on determinants of technologic progress such as; human capital, knowledge accumulation, education, research and development (R&D) and innovation. Endogenous growth models underline technological innovations in productivity as an output of investment on R&D. The firms which have innovated goods and services or production method with lower cost obtain international competition advantage that provide monopoly power or leader advantage.

An indispensable concept in the modern endogenous growth theory is creative destruction, defined by Schumpeter (1942). Creative destruction means that industries evolve with invention of new products and production processes by destroying old ones. The notion of creative destruction is important to clarify the reason behind imperfect competition and market failures that is crucial to understand growth patterns of developing countries in competition with developed ones. That is because, Schumpeter claimed that firms invest in R&D to obtain monopoly power and this leads imperfect competition in markets. Therefore, he criticized free market advocates of his time. Aghion and Howitt (1992) contributed to endogenous growth theory by incorporating the Schumpeterian creative destruction idea to a formal endogenous growth model. They stated that economic growth with technological progress is driven by market competition for innovation and evolution in market structure. One of the main findings of Aghion and Howitt (1992) is that stationary welfare equilibrium is influenced by strategic monopsony effect which can be defined as the influence of an intermediate firm on the amount of current research level and time of its replacement by increasing demand for skilled labor and higher wages eventually. Therefore the laissez-faire average growth rate may not be in optimal level.

Grosman and Helpman (1991a, P;1-33) stated that a causal reading of recent economic history indicates two trends: technological innovation become more important contributor to economic well-being and countries become increasingly more open and interdependent. Those trends are highly related to each other. Increasingly open and interdependent nations facilitate the process of invention and diffusion of technology and knowledge. And technological changes consolidated the consequences of more integrated world trade. While there are huge gaps between countries in terms of economic wellbeing, it is crucial to understand the effect of technological progress and structure of competition on economic well-being in this increasingly integrated world economy. Therefore, we will dwell on innovation processes and market structure that are the most important notions for the overall technological development.

2.4. Benchmark of Patent Race Models

The aim of this section is to form a basis for our model of patent race between asymmetric firms. That is why, we arranged the main findings of leading studies in this issue. In standard patent race models, investors behave strategically and rationally by considering current market equilibrium and returns of investment in R&D. The choice variable is the R&D investment which determines the invention date of a new superior technology. Patent races are multi agent-based models that show the competition between firms that invest in R&D to obtain a patent protection. Patent protection provide a future market power that enables firms to obtain high profits and to sustain innovative activities.

The patent race literature mostly assumes homogeneity of firms. The investment incentives of the firms depend on the current market power, the expected future return of innovation, and the market share after the technological invention.

The differences in R&D experience, past successful innovations and patents, learning by doing level and access to finance shape the decision processes of firms. However, the early patent race models are built upon the assumption that the only factor determining time of invention is the R&D expenditure.

Prominent authors of patent race literature [e.g. Loury (1979), Dasgupta and Stiglitz (1980) and Lee and Wilde (1980)] assumed that the success of innovation is a stochastic event. To be specific, the probability of success in R&D for any firm $i = 1,2, \dots, n.$ before time t is

$$Pr(\tau(x_i) \leq t) = 1 - e^{-h(x_i)t}$$

where $\tau(x_i)$ is the date of success and x_i is the investment level in R&D of the firm i. $h(x_i)$ is a hazard rate function that indicate the relationship between R&D investment of firm i and date of successful innovation. Expected value of time of introduction of new technology given by

$$E\big(\tau(x_i)\big) = h(x_i)^{-1}.$$

Reinganum (1989) and Loury (1979) takes the $h(.)$ as a twice differentiable and strictly increasing function of investment level of R&D. Further, it satisfies conditions that

I. $h(0) = 0 = \lim_{x \to \infty} h'(x)$,

II. $h''(x) \geq (\leq) 0 \; as \; x \leq (\geq) \bar{x}$

III. $\frac{h(x)}{x} \geq (\leq) h'(x) \; as \; x \geq (\leq) \tilde{x}$,

for some $(\bar{x}, \tilde{x})$ such that $0 \leq \bar{x} \leq \tilde{x} \leq \infty$.

The equilibrium level of patent races is a Cournot-style Nash equilibrium where all players decide optimal investment levels simultaneously to maximize their objectives that shall be discussed soon. The optimal $x_i(t)$ in equilibrium is necessarily time-independent since the race would end if a firm wins the patent race, and the game is identical to the initial point if no firm has won the race yet.

Proposition 1: The probability of firm i winning the patent race between time t and $t + dt$ is

$$he^{-\sum_i h(x_i)t} dt.$$

Proof: The probability of firm i winning the patent race is

$$\Pr\big(\tau(x_i) \in [t, t + dt] \; and \; \tau(x_j) > t \; for \; all \; j \neq i\big)$$

which is equal to

$$\Pr(\tau(x_i) \in [t, t + dt]\;) \times \Pr\big(\tau(x_j) > t\big).$$

Note that

$$Pr(\tau(x_i) \in [t, t + dt]\;) = \int_t^{t+dt} h(x_i) e^{-h(x_i)t} dt = -e^{-h(x_i)k}\Big|_{k=t}^{k=t+dt}$$

$$= e^{-h(x_i)t} - e^{-h(x_i)(t+dt)} = e^{-h(x_i)t}\big(1 - e^{-h(x_i)dt}\big)$$

$$\approx e^{-h(x_i)t} - h(x_i)dt.$$

Moreover,

$$Pr(\tau(x_i) > t\,) = e^{-h(x_i)t}.$$

Conclude that

$$Pr\big(\tau(x_i) \in [t, t + dt] \; and \; \tau(x_j) > t\,\big) = e^{-h(x_i)t} h(x_i) dt \times e^{-h(x_j)t}$$

$$= h(x_i) e^{-\sum_i -h(x_i)t} dt$$

as claimed. ■

The earlier studies on patent race employed general distribution functions for firms' investments on R&D as strategic factor. Loury (1979) developed a symmetric game theoretical model where firms have zero profit initially and the reward of innovation is same for the all firms, say P. Each firm discounts the value of winning the patent race with the expression of r that denotes interest rate. Let $a_i = \sum_{j\neq i} h(x_j)$ denote the aggregate rival hazard rate. In the symmetric case of the patent race, we can write the expected value of a representative firm as follows:

$$V(x_i, a_i) = \int_0^\infty Pe^{-rt}e^{-(a_i+h(x_i))t}h(x_i)dt - x_i$$

$$= \frac{Ph(x_i)}{r(r + h(x_i) + a_i)} - x_i.$$

Since the only strategic factor is the investment level, each firm maximizes its expected value respect to investment, simultaneously.

$$\max_{x_i}\left(\frac{Ph(x_i)}{r(r + h(x_i) + a_i)} - x_i\right).$$

After maximisation, we get the first order condition for firm i as:

$$\frac{h'(\hat{x})(r + a)}{(r + h(\hat{x}) + a)^2} - \frac{r}{P} = 0,$$

and the second order condition is

$$h''(\hat{x})(r + h(\hat{x}) + a) - 2h'(\hat{x})^2 \leq 0.$$

Based on the first order condition, we can define the best response function of a representative firm that depends on rival hazard rate, interest rate and the profit level after innovation; $\hat{x} = \hat{x}(a, r, P)$. Since the firms are symmetric, they have same best response function in equilibrium. Therefore, all firms employ same investment strategy and invest x^* level on R&D in equilibrium. $a = (n-1)h(x^*)$ indicates aggregate rival hazard rate of a representative firm as function of n. To understand the relationship between firms' investments and number of firms, we first need to find the derivative of best response function respect to a:

$$\frac{\partial \hat{x}(a, r, P)}{\partial a} = \frac{h'(\hat{x})\big(r + a - h(\hat{x})\big)}{(r + a)(h''(\hat{x})(r + h(\hat{x}) + a) - 2h'(\hat{x})^2)}$$

From the first and the second order conditions above we know the denominator of $\frac{\partial \hat{x}}{\partial a}$ is negative so the relationship between optimal investments and aggregate rival hazard rate depend on whether the hazard rate is greater than the sum of interest rates and aggregate rival hazard rate: $\frac{\partial \hat{x}}{\partial a} \geq (\leq) 0$ as $h(\hat{x}) \geq (\leq) r + a$. We know the firms are symmetric in terms of hazard rate function and they have same investment strategy in equilibrium. Therefore, we can say that increasing rivalry reduce the optimal investment because $r + a$ increase faster than $h(\hat{x})$.

As $n \geq 2$ and $\frac{\partial \hat{x}}{\partial a}$ is negative in equilibrium, we get the following proposition.

Proposition: The equilibrium investment level is a negative function of the number of firms; n: $\frac{\partial x^*}{\partial n} < 0$.

Proof: Given in equilibrium that $a^* = (n-1)h(x^*)$ and $x^* = \hat{x}\big((n-1)h(x^*), r, P\big)$, we get

$$\frac{\hat{x}\big((n-1)h(x^*), r, P\big)}{\partial n} = \frac{\partial \hat{x}}{\partial a}\frac{\partial a}{\partial \hat{x}}$$

$$= \frac{\partial \hat{x}}{\partial a}\left(h(x^*) + \frac{\partial h(x^*)}{\partial x^*}\frac{\partial x^*}{\partial n}(n-1)\right)$$

$$\frac{\partial x^*}{\partial n} = \frac{h(x^*)\,\partial \hat{x}/\partial a}{1-(n-1)h'(x^*)\,\partial \hat{x}/\partial a} < 0$$

■

Now we will discuss a common assumption in the field: a marginal increase in the equilibrium level of investment by any single rival firm leads to fall by a smaller amount of the investment of a given firm. Formally:

Assumption 1: $-h(x^*)\hat{x}'(a^*) < 1$.

Suppose that one rival firm increase it investment by dx; then $\frac{da^*}{dx^*} = h'(x^*)$. In this way the assumption above says that $-h'(x^*)d\hat{x} < h'(x^*)dx$, or $-d\hat{x} < dx$.

Proposition: Under the assumption 1, increasing number of firms always reduces the expected time of invention denoted by

$$E\tau(n) = \frac{1}{nh(x^*(n))}.$$

Proof: Expected time of invention declines with the number of firms in patent race if $\frac{d(nh(x^*(n)))}{dn} > 0.$

$$\frac{d\left(nh(x^*(n))\right)}{dn} = h(x^*(n)) + nh'(x^*(n))\frac{\partial x^*}{\partial a}\frac{\partial a}{\partial n}$$

$$= h(x^*(n))\left[1 + \frac{nh'(x^*(n))\,{}^{\partial \hat{x}}/_{\partial a^*}}{1-(n-1)h'(x^*(n))\,{}^{\partial \hat{x}}/_{\partial a^*}}\right]$$

From the proposition above,

$$\frac{d\left(nh(x^*(n))\right)}{dn} \geq (\leq) 0 \; as - h'(x^*)\frac{\partial \hat{x}}{\partial a} \leq (\geq) 0.$$

■

Under these propositions, Loury (1979) concludes that if one rival firm raises investment by one unit then other firms reduces their investment by the amount, $-h'(x^*)\frac{\partial \hat{x}}{\partial a}$ against the increase in aggregate rival hazard rate, a of $h'(x^*)$ in equilibrium.

Asymmetric patent race models that firms have different market shares and size, were also studied in literature. Tirole (1988) builds a model of a monopoly facing a potential entrant and analyse patent race between the monopolist and the potential entrant. In the model, which is actually a variant of Reinganum (1989), the monopolist invests in R&D conditionally on the absence of innovation before t and obtain the profit of $[\pi^m(\bar{c}) - x_1]dt$ where the $\pi^m(\bar{c})$ is the monopol profit with marginal cost without innovation, $\bar{c}$. The innovation is succeeded at time t + dt, where dt is an infinitesimal increment of time.

The monopolist becomes the first innovator with the probability of $h(x_1)dt$, and the discounted value of profit after the innovation is

$$\frac{\pi^m(\underline{c})}{r}$$

where $\pi^m(\underline{c})$ is the monopoly profit with marginal cost with innovation, $\underline{c}$. The entrant has the probability of $h(x_2)dt$ to become the first innovator and the monopolist's discounted value of profit after the innovation is

$$\frac{\pi^d(\bar{c},\underline{c})}{r}$$

that indicate the monopolist continue to operate in market with same marginal cost; $\bar{c}$, before innovation. The entrant starts to operate in market with innovated technology and obtains a duopoly profit of

$$\frac{\pi^d(\underline{c},\bar{c})}{r}.$$

Deduce that the expected values of a monopolist and an entrant are respectively as follows:

$$V_1(x_1,x_2) = \int_0^{\infty} e^{-rt}e^{-(h(x_1)+h(x_2))t}\left(\pi^m(\bar{c}) - x_1 + h(x_1)\frac{\pi^m(\underline{c})}{r} + h(x_2)\frac{\pi^d(\bar{c},\underline{c})}{r}\right)dt$$

$$= \frac{\pi^m(\bar{c}) - x_1 + h(x_1)[\pi^m(\underline{c})/r] + h(x_2)[\pi^d(\bar{c},\underline{c})/r]}{r + h(x_1) + h(x_2)}$$

$$V_2(x_1,x_2) = \int_0^{\infty} e^{-rt}e^{-(h(x_1)+h(x_2))t}\left(h(x_2)\frac{\pi^d(\underline{c},\bar{c})}{r} - x_2\right)dt$$

$$= \frac{h(x_2)[\pi^d(\underline{c},\bar{c})/r] - x_2}{r + h(x_1) + h(x_2)}.$$

Now, some inferences can be made about investment strategies of monopolies and entrants based on these expected values. Many studies on asymmetric patent race models are constructed by the intuitive assumption that a monopolist with the superior technology obtains more profit flow than total profit of a duopoly market.

$$\pi^m(\underline{c}) \geq \pi^d(\underline{c},\bar{c}) + \pi^d(\bar{c},\underline{c})$$

This assumption is called as efficiency effect. The numerators of V_1 and V_2, suggest that the monopolists have more incentive to innovate and therefore spends more on R&D. Reinganum (1989) stated that firms have two incentives to innovate. The first one is the stand-alone incentive that can be defined as innovation to increase profits.

The stand-alone incentive is $\pi^m(\underline{c}) - \pi^m(\overline{c})$ for a monopolist and $\pi^d(\underline{c}, \bar{c})$ for an entrant. The second is the incentive to pre-empt that can be defined as innovation to avoid losing which would reduce the current profit level. This given by $\pi^m(\overline{c}) - \pi^d(\bar{c}, \underline{c})$ for monopolists and zero for entrants that do not operate in market.

The replacement effect is another concept to explain investment strategies of asymmetric firms. This effectmeans that entrant firms invest in R&D for radical innovations, while monopolies target incremental innovations that improve existing technology with R&D. Radical innovations abolish old technologies and provide a monopoly profit for entrants while incremental innovations that provide a duopoly profit for entrant, $\pi^d(\underline{c}, \bar{c})$.

In addition, Tirole (1994) states that there is a negative relationship between the marginal productivity of R&D expenditure and initial profit for the monopolist:

$$\frac{\partial}{\partial \pi^m(\bar{c})} \frac{\partial V_1}{\partial x_1} < 0$$

This statement can be supported by the observation that the monopolist moves the discovery date forward by increasing its R&D investment; x_1 and therefore hastens its own replacement time. On the other hand, the entrant does not forgo a profit flow when succeeding in R&D. Either of the two effects may dominate. To see this, consider two case. As Tirole (1988) states, in drastic case equilibrium, a potential entrant's investment exceeds a monopolist's investment; $x_1^* < x_2^*$. Since the entrant becomes monopolist and don't let the others operate in market. However, in non-drastic case, even if entrants make invention, they start to operate in duopo

3. MODEL

In this study, we analyse a model of patent race between firms. Although the model is, by and large, similar to the standard patent race models, we extend the analysis in the following directions. The firms are categorized in two types such that incumbents that are technological leaders in a specific market and potential entrants of this market as in Gilbert and Newberry (1984) and Tirole (1988). The focus of our model is to show different decision processes for incumbent and entrant firms. The return of the successful innovation is differentiated for incumbents and entrants. In addition, the model includes the strategy of imitation for an entrant firm and its effects on R&D decisions of each type of firms and market structure.

In this context, our aim is to find the expected values of R&D in different non-cooperative patent race models and the optimal investment level for each type firm. We build different patent race models for two different market structures. In the first part, we introduce a model for a representative entrant to enter a market that incumbents operate in Bertrand competition where the strategical variable is pricing. In the second part, firms engage in a Cournot competition where output level is strategically decided. All these differences affect the R&D investment decisions of firms as well as market equilibrium profit level.

3.1. Patent Race between Firms That Operate in Bertrand Competition

Let us start our analysis with a model of a patent race between firms in Bertrand competition. All firms make zero profit initially since the equilibrium market price is equal to the marginal cost at the current technology of the incumbents; $\bar{c}$. The motivation of R&D for all firms is to be a monopolist. Therefore, they engage in a patent race to reduce production cost from $\bar{c}$ to $\underline{c}$. Let $p^m(\underline{c})$ become monopoly price with innovated production technology and lower marginal cost $\underline{c}$. As early patent race models state, there are two different cases that depend on the magnitude of this price. If $p^m(\underline{c}) \leq \bar{c}$, then the innovator obtains the monopoly proit denoted by $\pi^m(p^m)$ and other firms cannot continue to operate in this market and the entrants stay out of the markets. This case is called as drastic or major.

Another case is the non-drastic (minor) innovation that implies higher monopoly price the superior technology than the previous cost, $p^m(\underline{c}) > \bar{c}$. Then the innovator firm determines market price slightly below the losers' marginal cost; $(\bar{c} - \epsilon)$ to eliminate the other firms from the market. This price goes to $\bar{c}$ in the limit that ϵ goes to zero. Loser firms are obliged to stay out of market. This is often called "limit pricing": the pricing strategy according to which prices are determined to keep the entransts out the market. The innovator obtains a monopoly profit $\pi^m(\bar{c})$ with lower cost advantage and the others obtain zero profit again. Hence, in a Bertrand competition, without noticing drastic or non-drastic innovation, the innovator makes monopoly profit and the others make zero profit.

In our study, firms compete for a new technology that do not extinguish existing technology of incumbent firms. Due to a superior technology, current technology loses its market value and entrants can transfer the inferior technology cheaply (e.g. without any cost). The main object of the model is to understand the optimal strategy for an entrant between the choices for entry to the patent race or waiting for the end of patent race between incumbents.

Let us first analyse the case where entrants enter the race with the incumbents. In this case, a successful innovation is the only way to enter to the market for an entrant. Let x_I denote the R&D investment of incumbents and x_E is the R&D investment of entrants. In the non-drastic case, innovator firm obtains pricing power and a profit $\pi^m(\bar{c})$ with price slightly under the rivals' marginal cost while others make zero profit. Consequently, the expected values of R&D for a representative incumbent and entrant are as follows:

$$V_i = \int_0^{\infty} (\pi^m(p^m)\, h(x_i) - x_i) e^{-t(r+\sum_{i=1}^{n+2} h(x_i))} dt$$

$$= \frac{\pi^m(p^m)\, h(x_i)}{r(r + \sum_{I=1}^{2} h(x_I) + h(x_E))} - x_i \; for \; i = I, E.$$

The differences in expected value of innovation depend only on required investment level for early success for incumbents and entrants. We determine the different investment levels for success because of the heterogeneity between firms in terms of physical and human capital, stock of knowledge and R&D experience. Each firm determines the optimal investment level to maximize expected values. After maximization of this values as follows;

$$\max_{x_i}\left(\frac{\pi^m(p^m)\,h(x_i)}{r(r+\sum_{I=1}^{2}h(x_I)+h(x_E))}-x_i\right).$$

We get the optimization conditions as

$$\frac{h'(\widehat{x_\iota})\left(r+a^\iota\right)}{(r+\sum_{I=1}^{2}h(x_I)+h(x_E))^2}-\frac{r}{\pi^m(p^m)}=0\; for\; i=I,E.$$

Let assume firms' hazard rates are a linear function of investment levels with constant parameter; $h(\hat{x}_i)=\beta_i\,\hat{x}_i$ for $i=I,E$. Here β_i is the parameter that shows the effect of investments on firms' hazard rate and time of invention. When we solve the optimization conditions for incumbents and entrants, we get the expected value maximizing investment function; $\hat{x}_i(a_i,r,\beta_i,\beta_{-i},\pi^m(\bar{c}))$, interms of the rivals' hazard rate a^ι, interest rates, parameters of hazard functions for each type firm and profit level after innovation. Rival hazard rate of a representative incumbent is $a_I=h(\hat{x}_{-I})+h(\hat{x}_E)$ and of an entrant is $a_E=2h(\hat{x}_I)$. In Nash equilibrium, $x_i{}^*=\hat{x}_i(a_i{}^*) for\; i=I,E$ is the investment level.

The second strategy for a representative entrant is to wait until the end of the patent race between incumbents. In this case, there is still opportunity to enter the market. New innovated production method makes current technology of incumbents more affordable for an entrant with an insignificant cost. We assumed that the cost of transferring previous technology is zero because it is very low as compared to R&D cost for innovation. When only incumbent firms join the patent race for new technology, expected value of R&D for incumbents is as follows;

$$V_I=\int_0^\infty(\pi^m(\bar{c})\,h(x_I)-x_I)e^{-t(r+h(x_I)+h(x_{-I}))}dt$$

$$=\frac{\pi^m(\bar{c})\,h(x_I)}{r\left(r+h(x_I)+h(x_{-I})\right)}-x_I.$$

When we compare the expected values of incumbents for the strategies of entrants, the only difference is in the aggregate rival hazard rate that have negative affect on expected value. As we explained in section 2, equilibrium level of investment also depends on number of firms n, negatively; $\frac{\partial x^*(n)}{\partial n} < 0$. Therefore, expected time of success for a firm i; $E(\tau_i) = \frac{1}{h(x^*(n))}$, is an increasing function of number of firms. Thus, in case of entrants stay out of race, incumbents' expected time of success decreases.

As for the entrants' decision, the success of any incumbent allows the enterance to the market by the entrants with old technology of incumbents so potential entrants can enter the market without any R&D investment with zero profit. Thus, entrants make comparison between the expected value of patent race;

$$\frac{\pi^m\, h(x_E)}{r(r + \sum_{I=1}^{2} h(x_I) + h(x_E))} - x_E$$

and zero profit. At this point, the optimal investment level for innovation is main determinant of entry decisions.

3.2. Patent Race between Firms That Operate in Cournot Competition

A technological leader is spurred to innovate by both other technological leaders and potential entrants of market. As we stated in previous section, an incumbent has more incentive to innovate because those firms obtain more market power than entrants with a successful innovation. Also, the success of any other firm reduces the current profit of incumbents. That's why we can say that an incumbent firm always should consider entering in a patent race in order to continue to have the leader market power.

In this part, the model can be thought as a two-stage game that those two types of firms first simultaneously decide to whether enter to patent race or not and then choose their R&D investment levels if they choose to enter to patent race. Let us assume a Cournot market with two incumbent firms where both are symmetric and technological leaders, initially. They have the same marginal cost and identical production technology. In the first stage, strategy set of a representative incumbent firm is

$$S_I = \{ENTER,\ NOT\ ENTER\}.$$

A potential entrant has a strategy set; $S_E = \{ENTER, NOT\ ENTER\}$. However, the strategy of "not enter" implies that entrant firm can enter the market if one of the incumbent firms succeeds in R&D and create a new generation of technology. In this case, previous technology of successful incumbent becomes more affordable and imitatable for potential entrant. We constructed a matrix form game that shows strategy profiles of representative incumbents and a potential entrant.

Table 1: Strategic Form Patent Race Model

Incumbent \ Potential Entrant	Enter	Not Enter (Wait)
Enter	V_I^A, V_E^A	V_I^B, V_E^B
Not Enter	V_I^C, V_E^C	$\pi^C, 0$

One of the key points of this patent race model is that the reward of a successful innovation differs for incumbents and entrant. The strategy of waiting for the end of patent race also provides some level of profit for entrants. Hence, we must consider different competition structures in market. **In case A,** all firms enter the patent race and invest in R&D until the end of game. Two different market structures can appear with respect to type of innovator firm. If one of the incumbents succeeds in R&D, one leader and one follower Stackelberg competition occurs in the market and the entrant firm continue to stay out of market (π^L, π^F). If the entrant firms succeed in R&D then it enters into the market with new generation production process and obtains leader advantage. In this case a Stackelberg competition structure with one leader and two follower, occurs in the market (π^l, π^f, π^f). **In case B**, the incumbent firms enter to the patent race and potential entrants stay out of the patent race. If one of the incumbents succeeds in R&D then it becomes leader and the loser incumbent is obliged to share follower profit with the entrant firm (π^l, π^f, π^f). **The Case C** is an extreme strategy profile where incumbents do not enter patent race and a new firm chooses to invest in R&D for innovation. The success of the entrant firm leads to a Stackelberg competition with one leader and two followers (π^l, π^f, π^f). The payoffs of **Case D** state that there is no new firm in the market and the incumbents continue to operate with their current technology (π^C, π^C) under Cournot competition.

As a result, 3 plausible market structures can appear with respect to firms' investment decisions and the probabilities of success. Now we will clarify the expected profits for each firm for those 3 different market structure above (1. Cournot competition, 2.

Stackelberg competition with one follower and 3. Stackelberg competition with two followers). Let firms operate in a market with the following linear inverse demand function;

$$p = a - b\left(\sum_{i=1}^{n} q_i\right).$$

In the initial case and the case of no successful innovation, incumbents produce with a marginal cost $\bar{c}$ and operate in a Cournot competition with profit π^c. Profit level of a representative firm is

$$\pi^i = q_i\left[a - b\left(\sum_{i=1}^{2} q_i\right) - \bar{c}\right].$$

Each firm solves the following maximization problem with respect to the other firm's profit maximization problem

$$\max_{q_i} q_i\left[a - b(\sum_{i=1}^{2} q_i) - \bar{c}\right] \; s.t \; \max_{q_j} q_j\left[a - b(\sum_{i=1}^{2} q_i) - \bar{c}\right]$$

$$for \quad i \neq j.$$

First order condition for each firm is as follows;

$$a - \bar{c} - b\left(\sum_{i=1}^{2} q_i\right) - bq_i = 0.$$

By putting these two FOCs together, we obtain the same output level and same profit level for each firm.

$$p^c = \frac{a + 2\bar{c}}{3},$$

$$q_c = \frac{a - \bar{c}}{3b},$$

$$\pi^C = \frac{(a - \bar{c})^2}{9b}.$$

Stackelberg solution to one leader and *N* follower competition:

Step 1: Each follower solves following maximization problem simultaneously and respect to each other.

$$\max_{q_i} q_i \left[a - bq^l + \sum_{i=1}^{N} q_i - \bar{c} \right] \quad for\ i = \{1,2, \ldots, N\}$$

First order condition of a representative follower j is as follows

$$a - \bar{c} - bq^l - b\left(\sum_{i=1}^{N} q_i\right) - bq_j = 0.$$

N is the number of followers and we have N first order condition functions for each follower. After soloution of this equation system, we get following reaction function to leader's quantity for each follower

$$q_j = \frac{a - bq^l - \bar{c}}{4b}$$

Step 2: Put this into the leader's profit function and maximize;

$$P = \frac{a + N\bar{c} + (N+1)\underline{c}}{2(N+1)}$$

$$q^l = \frac{a + N\bar{c} - (N+1)\underline{c}}{2b}$$

$$q^f = \frac{a - (N+2)\bar{c} + (N+1)\underline{c}}{2(N+1)b}.$$

In case A, if one of the incumbents succeed in R&D, Stackelberg equilibrium profit level becomes as follows;

$$\pi^L = \frac{\left(a + \bar{c} - 2\underline{c}\right)^2}{8b}$$

$$\pi^F = \frac{\left(a - 3\bar{c} + 2\underline{c}\right)^2}{16b}.$$

If the entrant firm succes in R&D **in case A and in case C** and the entrant obtains existing technology of the winner incumbent **in case B** then Stackelberg equilibrium with two followers occurs as follows;

$$\pi^l = \frac{\left(a + 2\bar{c} - 3\underline{c}\right)^2}{12b}$$

$$\pi^f = \frac{\left(a - 4\bar{c} + 3\underline{c}\right)^2}{36b}.$$

We have computed the equilibrium profit levels of firms for those three cases. Those are the outcomes of patent races for firms. However, firms' decisions on innovation and imitation are also crucial for social welfare. Let us assume that social welfare is the total surplus which is the sum of firms' profits and the level of consumer surplus. Consumer surplus is the level of consumer benefits when the price that consumers are willing to pay exceeds the price that consumers pay. For the mathematical definitions see Mankiw (2012).

Cournot competition; this market structure implies the initial competition dynamics between incumbents. Further, this structure can occur when no firm succeed in R&D in each strategy profile. The consumer surplus under cournot competition is as follows

$$CS^C = \frac{2(a-\bar{c})^2}{9b}.$$

The success of any firm leads to appear a Stackelberg competition in each case. The equation below shows the value of consumer surplus for a market with one leader and N follower.

$$CS^S = \frac{\left((2N+1)a - N\bar{c} - (N+1)\underline{c}\right)^2}{8(N+1)^2 b}$$

Now, we can calculate change in social welfare (Assume that social welfare is sum of profits of firms and consumer surplus with new market structure.) with respect to initial Cournot competition.

$$W^C = \frac{4(a-\bar{c})^2}{9b}$$

If the market involves a Stackelberg competition with one leader and one follower, then social welfare is

$$W^{S1} = \frac{4\left(a+\bar{c}-2\underline{c}\right)^2 + 2\left(a-3\bar{c}+2\underline{c}\right)^2 + \left(3a-\bar{c}-2\underline{c}\right)^2}{32b}.$$

If the market involves a Stackelberg competition with one leader and two followers, then social welfare is

$$W^{S2} = \frac{6\left(a+2\bar{c}-3\underline{c}\right)^2 + 4\left(a-4\bar{c}+3\underline{c}\right)^2 + \left(5a-2\bar{c}-3\underline{c}\right)^2}{72b}.$$

Let ΔW^{S1} and ΔW^{S2} show the changes in social welfare for Stackelberg competition with one and two followers.

$$\Delta W^{S1} = \frac{4\left(a+\bar{c}-2\underline{c}\right)^2 + 2\left(a-3\bar{c}+2\underline{c}\right)^2 + \left(3a-\bar{c}-2\underline{c}\right)^2}{32b} - \frac{4(a-\bar{c})^2}{9b}$$

and

$$\Delta W^{S1} = \frac{6\left(a+2\bar{c}-3\underline{c}\right)^2 + 4\left(a-4\bar{c}+3\underline{c}\right)^2 + \left(5a-2\bar{c}-3\underline{c}\right)^2}{72b} - \frac{4(a-\bar{c})^2}{9b}.$$

Those equations are important to discuss the possible benefits of innovation and imitation for firms and society. We will return to those again in calibration of madel and discussion on policy implications of innovation.

Table 2 shows the possible profit levels for each firm for cases of success and fail in **the case A.** The notation of "FF" implies that all firms fail in innovation and market equilibrium occurs as in initial case. "SF" notates the success of any incumbent that results in a Stackelberg equilibrium with one leader and follower. The success of any representative entrant "FS" provides the first mover advantage with two followers.

Table 2: Expected Profits Of Each Firm For Case A

	Incumbent	The other incumbent	Entrant
FF	π^C	π^C	0
SF	π^L	π^F	0
FS	π^f	π^f	π^l

Now we can write expected payoffs of firms that choose to enter the patent race. Since the incumbents and the potential entrant are asymmetric in terms of expected profit levels and optimal investment of R&D, we write different payoffs for each representative firm of incumbents and entrant respectively.

$$V_I^{\,A} = \int_0^{\infty} \left(\pi^L h(x_I) + \pi^F h(x_{-I}) + \pi^f h(x_E) + \pi^C - x_I\right) e^{-t(r+h(x_I)+h(x_{-I})+h(x_E))} dt$$

$$= \frac{\pi^L h(x_I) + \pi^F h(x_{-I}) + \pi^f h(x_E) + \pi^C}{r(r + h(x_I) + h(x_{-I}) + h(x_E))} - x_I.$$

and,

$$V_E{}^A = \int_0^\infty (\pi^l h(x_E) - x_E) e^{-t(r+h(x_I)+h(x_{-I})+h(x_E))} dt$$

$$= \frac{\pi^l h(x_E)}{r(r + h(x_I) + h(x_{-I}) + h(x_E))} - x_E.$$

Using proposition 1 and possible profits that are defined in appendix 1, we can show how expected value of R&D differ for an incumbent and a potential entrant. Investment level x_i is a strategic factor that determines firms' success. The best response function of investment level $\hat{x}_i(.)$ depends on firm's own hazard rateand aggregate rival hazard rate. At the optimal investment function of x_I and x_E,

$$V_I{}^A(\hat{x}_I(a^I), a^I) \geq V_I{}^A(x_I, a^I)$$

for representative incumbents for all $a_I = h(x_{-I}) + h(x_E)$ and

$$V_E{}^A(\hat{x}_E(a^E), a^E) \geq V_E{}^A(x_E, a^E)$$

for a representative entrant for all $a^E = h(x_I) + h(x_{-I})$. To obtain these functions, we maximize the expected payoffs of each type of firm respect to x_i as:

$$\max_{x_I} \left(\frac{\pi^L h(x_I) + \pi^F h(x_{-I}) + \pi^f h(x_E) + \pi^C}{r(r + h(x_I) + a_I)} - x_I \right)$$

and,

$$\max_{x_E} \left(\frac{\pi^l h(x_E)}{r(r + a_E + h(x_E))} - x_E \right).$$

The central feature of the model that we employ in this paper is that the optimal investment level is different for a potential entrant because of some externalities that affect return of R&D investments as well as differences in expected profits. An incumbent has R&D experience and know-how about the industry and that provides more efficient R&D process for early success. Past R&D experiences and know-how cannot be transferred timelessly and at no cost, so an entrant should consider these costs too. Because of these reasons, incumbents have stronger incentives to increase investment and probability of early success.

We deduce following optimization conditions for each representative firm from above maximization problems. For an incumbent, optimization condition is

$$\frac{h'(x_I)}{(r+h(x_I)+a_I)^2} - \frac{r}{h(x_{-I})(\pi^L-\pi^F)+h(x_E)(\pi^L-\pi^f)+r\pi^L-\pi^c} = 0$$

and for an entrant;

$$\frac{h'(\hat{x}_E{}^A)}{\left(r+a_E+h((\hat{x}_E{}^A))\right)^2} - \frac{r}{\pi^l(r+a_E)} = 0\,.$$

$\hat{x}_I{}^A(.)$ and $\hat{x}_E{}^A(.)$ are best response functions of each representative firm respect to their own hazard rate and aggregate rival hazard rates; a_I and a_E respectively. Solving these equations simultaneously gives us Nash equilibrium investment levels such that $x_I{}^{A*}$ maximizes V_I^A for given $x_E{}^{A*}$, and $x_E{}^{A*}$ maximizes V_E^A for given $x_I{}^{A*}$.

Secondly, consider **the case B** that the representative entrant firm chooses to wait until one of the incumbents succeed in R&D. The key point of this case is that success of any incumbent enables potential entrant to have existing technology with zero cost. At this point, winner of the race becomes leader of market with two followers; the other incumbent and potential entrant. *Table 3* shows possible profits level for each firm in different situations. π^l is the profit of the leader with two followers. π^f is the profit of loser incumbent and entrant. In case of no winner in the race, two incumbents continue to operate in Cournot competition with profit π^C.

Table 3: Expected Profits Of Each Firm For Case B

	Incumbent	The Other Incumbent	Entrant
FF	π^C	π^C	0
SF	π^l	π^f	π^f

Similar to case A, we can compute the expected profits for incumbents and potential entrants. Since the representative entrant chooses to wait the end of the patent race between incumbents, it has no choice variable at this stage. The expected values of incumbents and entrants are as follows;

$$V_I{}^B = \int_0^\infty (\pi^l h(x_I) + \pi^f h(x_{-I}) + \pi^C - x_I)e^{-t(r+h(x_I)+h(x_{-I}))}dt$$

$$= \frac{\pi^l h(x_I) + \pi^f h(x_{-I}) + \pi^C}{r(r + h(x_I) + h(x_{-I}))} - x_I$$

and

$$V_E{}^B = \int_0^\infty \left(\pi^f h(x_I) + \pi^f h(x_{-I})\right) e^{-t(r+h(x_I)+h(x_{-I}))}dt$$

$$= \frac{\pi^f (h(x_I) + h(x_{-I}))}{(r + h(x_I) + h(x_{-I}))}.$$

At this point, the incumbents are the only players that can affect the result of the game via investment on R&D. They maximize the expected values and this process affect the decision of entrants. The maximization problem is

$$\max_{x_I} \left(\frac{\pi^l h(x_I) + \pi^f h(x_{-I}) + \pi^C}{r(r + h(x_I) + h(x_{-I}))} - x_I \right).$$

for which the first order necessary optimality condition is;

$$\frac{h'(x_I)}{(r + h(x_I) + h(x_{-I}))^2} - \frac{r}{h(x_{-I})(\pi^l - \pi^f) + r\pi^l - \pi^C} = 0$$

After solving this maximization condition, we obtain the optimal investment functions of incumbents that depend on interest rates, hazard rates of both and profit levels respect to result of game and number of entrants that wait end of the race. Let $\hat{x}_I{}^B(.)$ denote the best response function of a representative incumbent respect to their own hazard rate and aggregate rival hazard rates. $x_I{}^{B*}$ maximizes V_I^B.

In the case C, only potential entrant invests in R&D but incumbents do not invest. *Table 4* shows possible profits level for each possible situation. Potential entrant enters the market with successful innovation or stay out of the market by failing in innovation. In case of success, entrant firm becomes leader firm with innovated production technology and lower marginal cost.

Table 4: Expected Profit Of Each Firm For Case C

	Incumbent	The Other Incumbent	Entrant
F	π^C	π^C	0
S	π^f	π^f	π^l

Since the incumbents do not enter to the patent race, their expected value depends on completely R&D process of potential entrant. A successful innovation of entrant firm ends the market power of incumbents. The expected values of each representative firm is as follows;

$$V_I{}^C = \int_0^\infty (\pi^f h(x_E) + \pi^C) e^{-t(r+h(x_E))} dt$$

$$= \frac{\pi^f h(x_E) + \pi^C}{r + h(x_E)},$$

$$V_E{}^C = \int_0^\infty (h(x_E)\pi^l - x_E) e^{-t(r+h(x_E))} dt$$

$$= \frac{\left(\pi^l h(x_E)\right)}{r\left(r + h(x_E)\right)} - x_E.$$

The entrant firm determines the optimal investment as the only choice variable to maximize expected value. This case is identical to early patent race models.

$$\max_{x_E} \left(\frac{\left(\pi^l h(x_E)\right)}{r\left(r + h(x_E)\right))} - x_E \right)$$

$$\frac{h'(x_E)}{\left(r + h(x_E)\right)^2} - \frac{r}{\pi^l \left(r + h(x_E)\right)} = 0.$$

Let $x_E{}^{C*}$ be optimal investment for entrant that maximizes V_E^C. The maximization of the entrant's expected value gives us the optimal investment function for successful innovation respect to the rival's hazard rate and number of firms in patent race.

In the case D that all types of firms do not invest in R&D, market structure remains unchanged. Incumbents continue to operate in a Cournot competition with profit π^c and potential entrant cannot enter the market.

4. CALIBRATION OF MODEL WITH DATA OF MOBILE PHONE SECTOR

In section 3, we have focused on the dynamics of a patent race between asymmetric firms and alternative strategies for a follower firm to enter a specific market theoretically. In this section, the model will be calibrated with the data of technological leaders in mobile phone market; Apple and Samsung.

In accordance with our theoretical model, it is assumed that these firms compete in Cournot competition and produce identical products. This assumption can be supported by observation that Apple and Samsung produce approximately the same quality of products. Even if there are many firms in mobile phone sector, these firms produce low quality products except Apple and Samsung. Therefore, we can assume those firms are in a Cournot competition that share the demand in high-quality mobile phone market. In 2011, total market share of these two firms is 38% and they split it evenly. Average unit price and unit cost of these firms are approximately 1337 USD and 860 USD respectively. Their total sales are about 187 Million units (Annual financial reports of Apple, Samsung and Huawei).

In Cournot markets, we know that

$$\frac{P-c}{P} = -\frac{1}{n\,E_D}.$$

where P and c are unit price and unit cost respectively. $n\,E_D = E_d$ is the firm's elasticity of demands and E_D is market elasticity of demand. By the help of market elasticity of demand we get the slope of inverse demand function and we already know that this function pass the point that quantitiy is 187 million and price is 1337 USD (The numbers are rounded down to make calculations simplier). As a result we computed the following inverse demand function:

$$P^m = 2292 - 5.08Q^m.$$

This demand function provides necessary profit levels in million USD for the cases that innovation reduces costs by 5%, 25% and 50% by the assumption that interest rate is 0.05 (Table 5).

Table 5: Estimated Profit Levels From The Market Demand Function Above.

The Level Of Cost Reduction	π^L	π^F	π^c	π^l	π^f
5% (from 860 USD to 817 USD)	56,700	22,289	44,851	39,972	9,283
25% (from 860 USD to 645 USD)	85,311	12,352	44,851	70,766	3,386
50% (from 860 USD to 430 USD)	129,150	4,011	44,851	121,454	109

In 2011, Samsung invested approximately 9100 million USD and Apple invested only 2400 million USD for R&D. Huawei is another firm that have a market share under 4%, invested 3668 million USD for R&D in 2011. In 2017, While Samsung's market share reached to 22%, Apple's share is reduced by 4 percentage point and becomed 15%. Huawei increased its market share to 11% in 2017 (Annual financial reports of Apple, Samsung and Huawei)

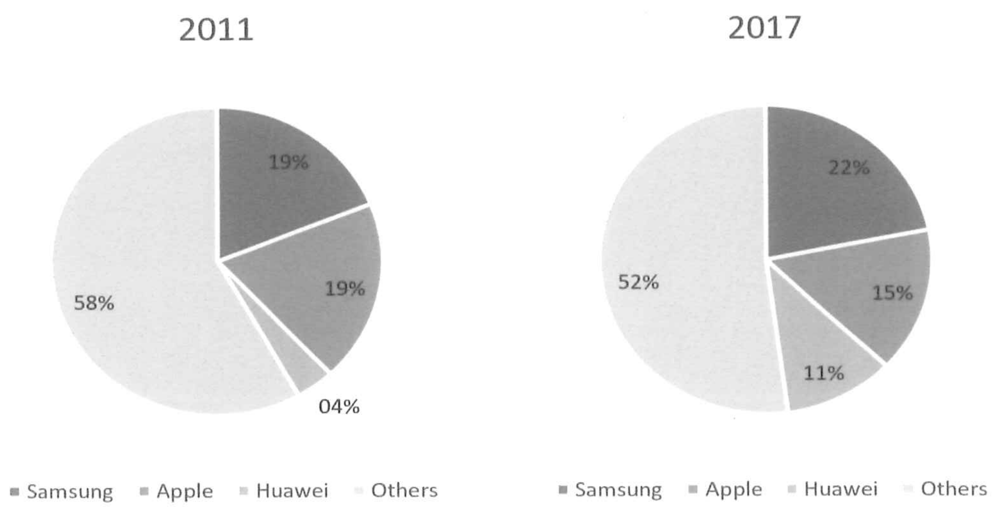

Figure 1: Market Shares in Mobile Phone Sector in Years 2011 and 2017.

Source: IDC Marketscape, https://www.idc.com/.

From 2011 to 2017, Apple invested 45,990 million USD for R&D in total while Samsung made R&D expenditure by 88,771 million USD. In same period, total R&D expenditure of Huawei was 53,333 million USD that is more than Apple's expenditure.

Table 6: R&D Expenditures of Apple, Samsung and Huawei

	Apple	**Samsung**	**Huawei**
2011	2,400	9,100	3,668
2012	3,381	11,052	4,775
2013	4,475	13,997	5,070
2014	6,041	13,869	6,588
2015	8,067	12,659	9,170
2016	10,045	12,536	11,007
2017	11,581	15,558	13,055
Total	**45,990**	**88,771**	**53,333**

Source: Annual financial reports of Apple, Samsung and Huawei.

Therefore, we accept the R&D expenditure of Samsung as optimal investment for a representative incumbent firm (9,100 million USD) and Huawei's R&D expenditure as optimal investment level for the entrant firm (3,668 million USD) in case A. One of the key points of this model that differs from early studies, is the differentiated hazard rate function parameters that refers to the return of R&D expenditure on expected time of invention for incumbent and entrant firms. Different hazard rate functions provide a wider perspective on R&D investments of heterogeneous firms in terms of the effect of investment on time of early success. We assume that firms have linear hazard function such that $h(x_i) = \beta_i x_i$ in order to make interpretation about the the effects of these parameters. In the model, we calculated first order conditions to find the optimal investments for incumbents and entrant firms in case A that each type of firms choosed to enter to patent race. These conditions are as follows for incumbents and entrants;

$$\frac{h'(x_I)}{(r + h(x_I) + a_I)^2} - \frac{r}{h(x_{-I})(\pi^L - \pi^F) + h(x_E)(\pi^L - \pi^f) + r\pi^L - \pi^c} = 0$$

and

$$\frac{h'(\hat{x}_E{}^A)}{\left(r + a_E + h((\hat{x}_E{}^A))\right)^2} - \frac{r}{\pi^l(r + a_E)} = 0,$$

respectively.

By the substitution of corresponding values in these equations, we calculate the hazard rate function parameters for the cases that innovation reduces costs by 5%, 25% and 50%, (Table 7).

Table 7: The Hazard Rate Function Parameters And Difference Between Expected Values Of Potential Entrant For The Case A And Case B.

Cost Reduction	β_I	β_E	$V_E^B - V_E^A$
5% (from 860 USD to 817 USD)	0.00014	$\frac{3.3}{10^6}$	9101
25% (from 860 USD to 645 USD)	0.000062	$\frac{8.41}{10^7}$	3240
50% (from 860 USD to 430 USD)	0.000034	$\frac{2.77}{10^7}$	95.4

Let first look at the effect of hazard rate function parameters on optimal investments of incumbents and entrants:

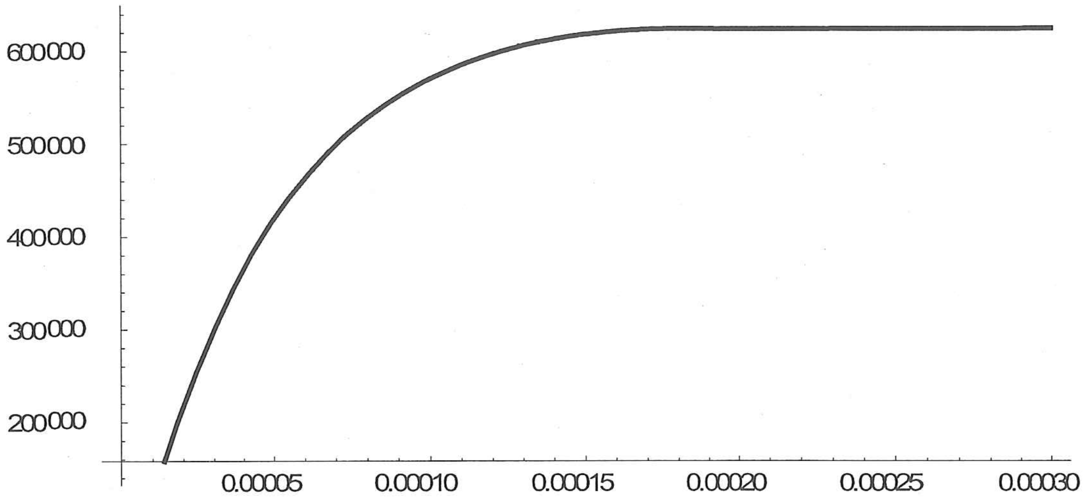

Figure 2: Invesment Of İncumbent Firms Respect To β_I (From 0 To 0.0003) As $\beta_E = 0.0001$.

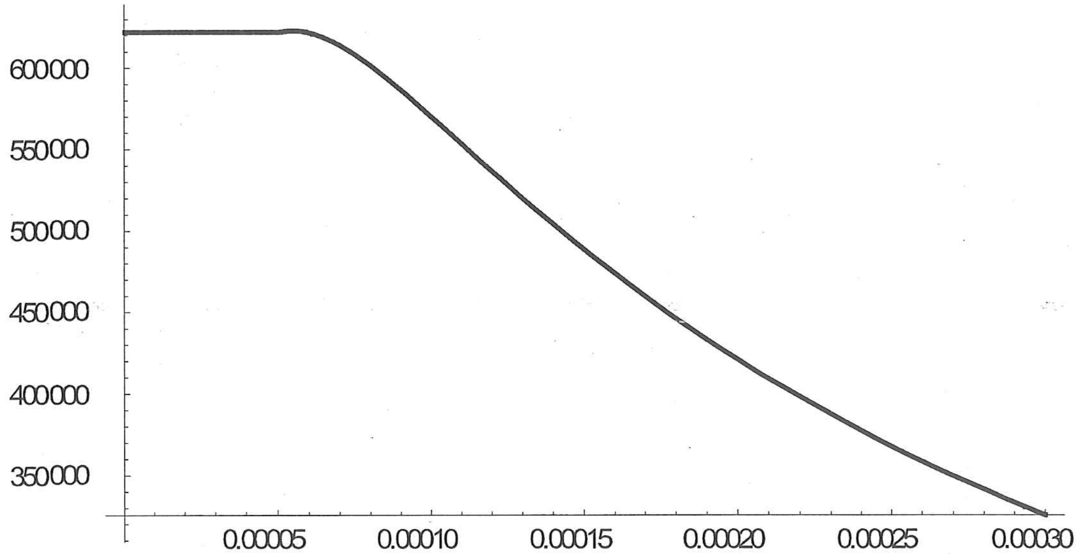

Figure 3: Investments Of Incumbents With Respect To β_E (Between 0 And 0.0003) Given $\beta_I = 0.0001$.

Figure 2 shows the optimal investment levels of a representative firm respect to the changes in its own hazard rate function parameter β_I from 0 to 0.0003 as $\beta_E = 0.0001$. The expected positive reaction of β_I on incumbents' investments is valid as long as $\beta_I < \beta_E$. If $\beta_I > \beta_E$, since the entrant firm is not a threat for incumbents, it is unnecessary to increase investments. As is seen in figure 3, the changes in β_E do not affect investment decisions of incumbents as $\beta_E < \beta_I$. After β_E becomes higher than β_I, R&D invesments of incumbents react ot changes in β_E negatively.

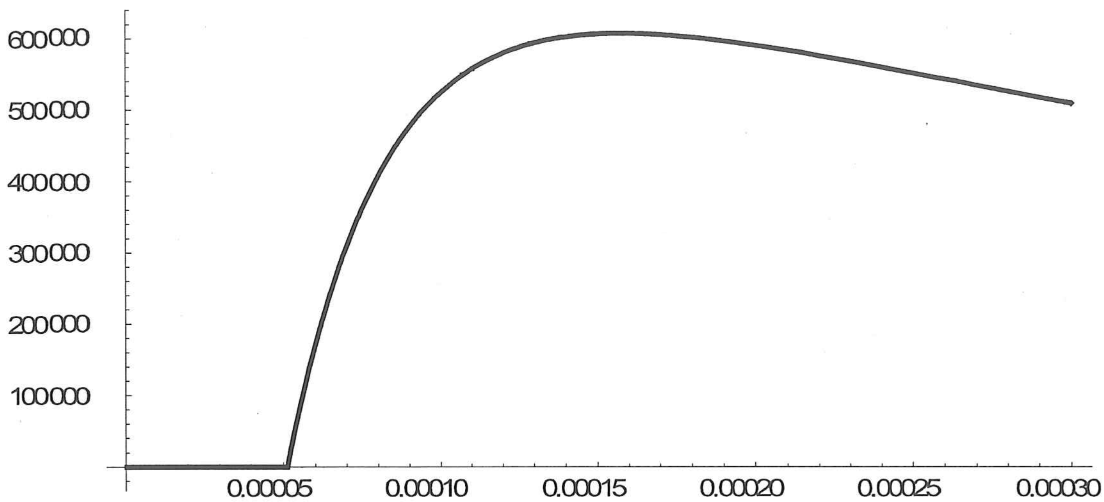

Figure 4: Investments of entrant respect to β_E (from 0 to 0.0003) as $\beta_I = 0.0001$

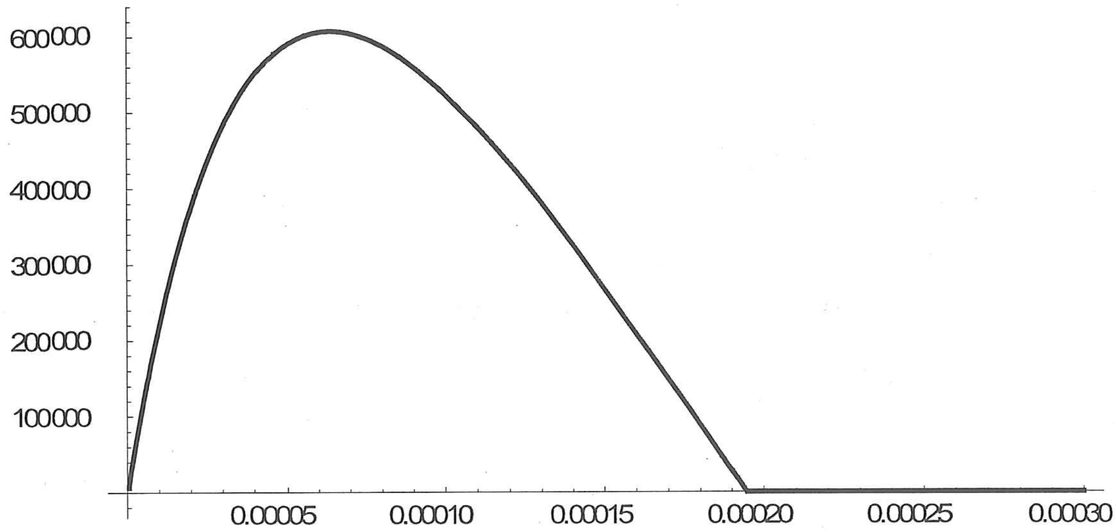

Figure 5: Investments Of Entrant Respect To β_I (From 0 To 0.0003) As $\beta_E = 0.0001$.

In figure 4 and 5, optimal investment levels of entrant firm are shown with respect to changes in its own hazard rate function parameter and incumbents' hazard rate function parameters. The reaction of entrant firm's investments to β_E is positive as long as $\beta_E < \beta_I$. After β_E exceeds β_I, the effect of changes in its own parameter becomes negative but this effect is not strong.

If a representative firm has lower return of R&D expenditure on expected invention date, the positive changes in its own parameter motivate this firm to invest more. If a firm, whichis already behind the others in terms of R&D efficiency, opts to enter patent race, this firm would make more R&D expenditure to utilize opportunuity of early success. In other words, if R&D efficiency gap with rival firms increase then this representative firm reduces its R&D expenditure due to lower probability of early success.

In figure 6, we see the difference between expected sum of discounted profits of an entrant due to choosing the patent race or imitiating the leaders. The hazard rate function parameters are estimated by assuming that the optimal investment of an incumbent is 9100 million USD (Samsung's R&D expenditure) and that of an entrant is 3668 million USD (Huawei's R&D expenditure). According to Figure 6, waiting for the end of the patent race between incumbents and imitating current technology is more profitable for the potential entrant when innovation reduces the production cost from 860 USD to only 817 USD. The difference between expected value of case B and case A is 9101. Knowledge accumulation through imitation or other structural changes that increase R&D efficiency of entrants makes entering to patent race more profitable for entrant firms (figure 6).

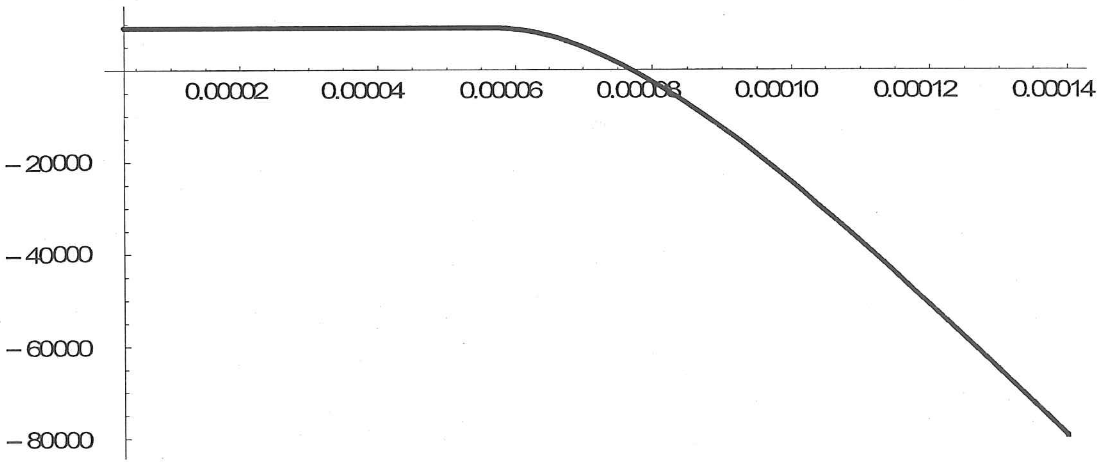

Figure 6: The Reaction Of $V_E^B - V_E^A$ To Changes In β_E As The Cost Reduction Is 5%.

When we assume that successful innovation reduces production cost by 25%, difference between expected values of potential entrant for case B and case A is computed as 3240.

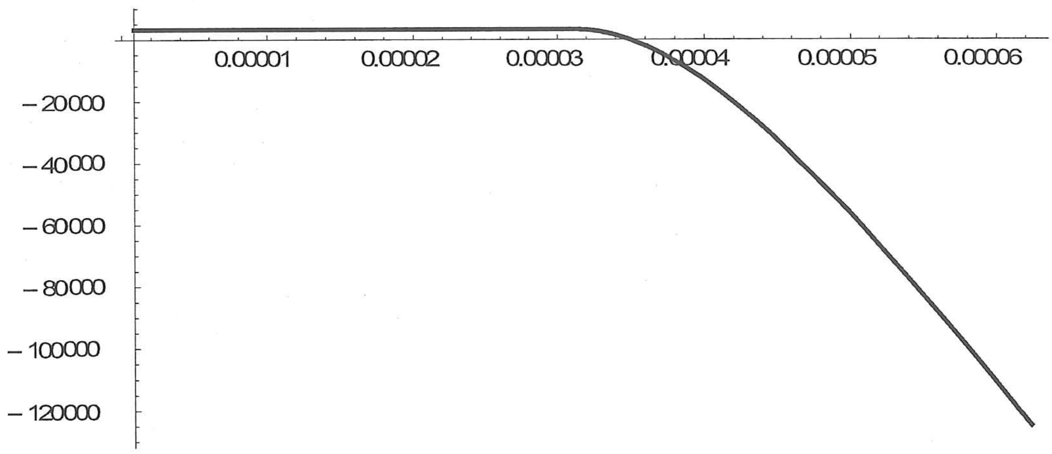

Figure 7: The Reaction Of $V_E^B - V_E^A$ To Changes In β_E As The Cost Reduction Is 25%.

When cost reduction is 50%, the difference between V_E^B and V_E^A is 95.4 so we can say that when innovation becomes more drastic, it is more profitable/lucrative to invest in innovation for potential entrants.

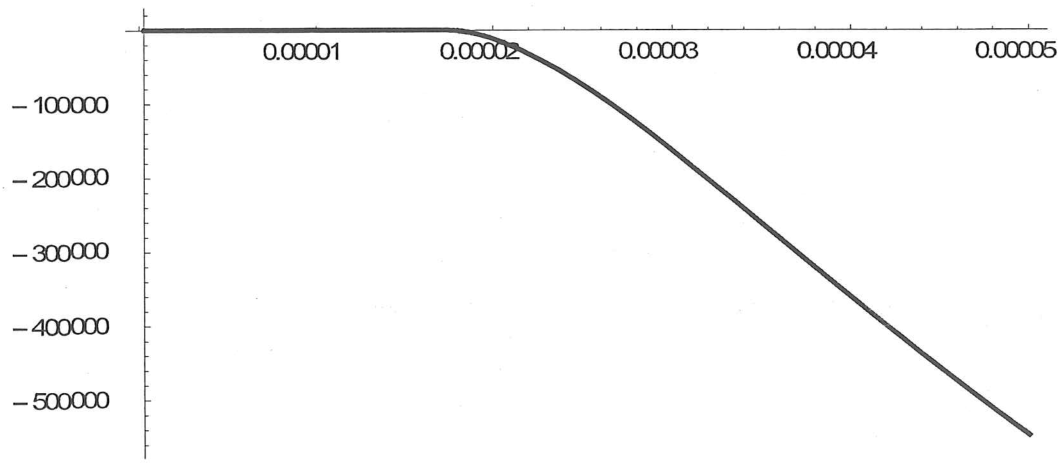

Figure 8: The Reaction Of $V_E^B - V_E^A$ To Changes In β_E As The Cost Reduction Is 50%.

Note that in the first stage, the entrant firm decides to whether enter to patent race or not. The firms which choose to enter to the patent race, start to make R&D investments that will determine the payoffs of initial decisions of the firms. We investigated the case of Huawei that had been making R&D investments for innovation. Hence, Huawei is an entrant firm that already decide to enter to patent race. Based on this fact, we can assume that the patent race between Apple, Samsung and Huawei represents the case A in our theoretical model. By this assumption, we calculated the unknown hazard rate function parameters under different cost reduction levels. In 2017, Samsung has made the largest level of R&D investment and increased its market share to 22% so we assumed it is a successful innovater and we accepted its R&D investment as an optimal for incumbents. In this year, although Huawei has made more R&D expenditure than Apple, it still has lowest market share than the others. These level of R&D expenditure of Huawei can be interpreted as an irrational choice but there are some other factors that make patent race rational for Huawei such that government grants for its contributions to research and development in the People's Republic of China (PRC) by amount approximately 2260 million USD from 2011 to 2017 (Annual financial reports of Huawei from 2011 to 2017. We made calculations with the end year Exchange rate of CNY/USD). In addition, as Liu, Zheng and Wei (2012) stated, Huawei has an imitation history before it started to make R&D expenditure for innovation and market leadership. It is expected that imitation increases the return of R&D expenditure on time of innovation (the hazard rate function parameter) through knowledge accumulation and learning by doing. As conclusion, Huawei has maken a progress before enter patent races by imitation experiences. Now, even if it still not as efficient as leader firms in R&D, it chooses to make R&D expenditure for innovation by the help of some level of government grants and some advantages in domestic market of PRC that is resulted from the national economic policies.

Welfare analysis

Until now, we have focused on the value of technological innovation to firms that are the main players in R&D invesments. However, as seen in Huawei case, technology is not just a phnomenan that affect firms' profits, it is also a national policy object and affects social welfare. Policy makers interested in not only firms' benefits but also how social welfare is changed by new market structure.

We have computed the equations for firms's profits and the change in social welfare under different market structure in our model. By the help of those equations, we estimated plausible profit levels with data of mobile phone sector in Table 5. We will estimate the effect of innovation and imitation on social welfare now. Cournot competition is initial market structure that consumer surplus is

$$CS^C = \frac{2(a-\bar{c})^2}{9b}$$

$$= 89{,}678$$

$$for\ a = 2{,}292 \quad b = 5.08 \quad and \quad \bar{c} = 860\,.$$

In initial case, social welfare is

$$W^C = 2\,\pi^C + CS^C$$

$$= 89{,}702 + 89{,}678$$

$$= 179{,}380$$

In Table 8, we have showed the estimated consumer surplus and social welfare and the change in in social welfare welfare for the cases of Stackelberg competition that can appear as a result of our model.

Table 8: Estimated consumer surpluses for different cases

The Level of Cost Reduction	CS^{S1}	CS^{S2}	W^{S1}	W^{S2}	ΔW^{S1}	ΔW^{S2}
5%	118,089	145,217	197.078	203,755	17,698	24,375
25%	137,362	166,510	235.025	244,048	55,646	64,669
50%	163,501	195,175	296.662	316,846	117,283	137,467

It is deduced from table 8, when the entrant firm enters the market by innovation or imitation (one leader and two followers), the change in social welfare is more than the case that incumbents make technological innovation imitation (one leader and one follower). That is because of increasing competiton by new entry without noticing by innovation or imitation. In addition, there no difference the returns of innovation and imitation strategies of entrants in terms of benefits of overall society. However, as in Huawei case, economic policies are implied for national banefits and targets. Hence, if we assume entrant firms are from developing aconomies that technologically behind advanced countries, the change in national welfare can be more with innovation for developing economies because of higher profit level for entrants with innovation. We ignore the possibility of lower consumer surplus that reduce leader profit in developing economies. The idea behind this assumption is that the most of market demand comes from developing economies in mobile phone sector due to high population. Developing economies like China and India had approximately 28 % and 10 % of total world smart phone users and the annual growth of smartphone users in these countries is 19.5% for India and 7.6% for China. Hence, we can say that developing countries benefit from changes in consumer surplus more than developed economies. In next section, we will discuss this topic and policy implications of innovation in more detail in next section.

5. A DISCUSSION ON POLICY IMPLICATIONS

In this chapter, we will focus on the policy implications of innovation and imitation by considering development levels of economies. Our model and calibration showed that in many cases it is more rational to imitate the older technologies for new firms and the entry of a new firm to markets causes more increase in social welfare independently of that entrant firm is an innovator or imitator. In the direction, we will focus on national economic policies of developed and developing countries. It would be appropriate to assume the asymmetries between firms are valid for countries. We can assume that incumbent firms are from developed economies and entrant firms are developing economies. In this context, Stiglitz (2015) discusses different policy proposals for technological leader and follower countries. One of the most important conclusions of this article is that remaining as laggard for countries that are technologically behind the advanced countries, is optimal and their preference in equilibrium. His conclusion is supported by our model and calibration. Stiglitz explains the reason behind this result bu arguing that laggard countries sufficiently benefit from diffusion of leaders' knowledge. According to Stiglitz, both kind of countries implement innovation policies. However, leader countries pursue policies to open technological gap with laggards, so followers should imply appropriate policies to protect own technology intensive sectors and close the gap with technological frontiers. Currently, many advanced countries that want to sustain their economic growth through innovation, set innovation strategies such as; Japan has proposed "digital Japanese innovation plan", South Korea introduced a "creative economic plan" and the USA has launched a "technological innovation plan" (TIP) and "the American innovation strategy". Innovation oriented development strategies are crucial to sustain economic growth and to reach development goals of those countries.

As we stated in our model, there is a significant level of difference between the probabilities of early success of incumbent and entrant firms. Because of that, imitation is more rational for entrant firms. Imitation also constructs a basis for R&D project for innovation by increasing level of know-how, learning by doing and efficiency of R&D

investments. After firms obtains some experience on imitation, they start for R&D for new technologies that will reduce the gap between leader and new firms. Hence, imitation is not compatible with the interest of incumbent and technological leaders for two reasons; first, it reduces their current profits with new actors in market and second reason is that new firms become a threat for next patent races through increasing R&D efficiency. Advanced economies imply economic policies that prevent imitation of their advance technologies by developing economies as Intellectual Property Right (IPR) protection policies.

Chang (2001) provides a closer look of intellectual property right (IPR) policies that affects technological progress and its diffusion via laws and regulations. Chang (2008) claim that Trade-Related Intellectual Property Rights (TRIPS) increased the barriers to access new knowledges that is a need for development of developing countries. This agreement has broadened the scope of IPR protection and enlarged time of protection. In theoretical perspective, his study postulated that TRIPS agreements discourage developing countries to make technological progress through informal channels (imitation, modification or adaption of technologies from advanced countries). However, increasing private intellectual property right (PIPR) in developing countries leads more transferring technology through formal channels from advanced countries.

In our study, we made analysis on social welfare by assuming each type of firms operate in same society. However, national economic policies consider benefits of domestic firms. As we stated above, while developed countries aim to protect technologically advanced incumbent firms using IPR policies, developing economies aim to close the technological gap with advanced economies through imitation that will construct a basis for new research and innovation after increase R&D efficiency through imitation and some other economic policies. Especially, developing economies should consider other policy tools that prepare their economic system for innovation such that entrepreneurial institutions and social capital. Those policy tools can be considered as other factors that increase efficiency of R&D investment for innovation as well as imitation.

One of the most crucial factors that determine innovation and imitation level in economies is social capital. Akçomak and ter Weel (2009) and Thompson (2018) found strong positive relationship between innovation and economic growth by underlying the importance of social capital for an innovation economy in their empirical studies. The idea is that well educated, participative and globally networked society contribute to economic growth with innovation. Akçomak and Bas (2009)'s empirical study on 102 European regions, suggests that less developed regions have problems to make progress in technology and per capita income growth since transformation of society to promote sustainable development takes long time. They concluded that public investment in R&D may not be the most effective way to promote growth since private sector still be inefficient to make R&D investment. At this stage, their policy suggestion is a well-formed education system that spur society to make right decisions and underlined the fact that human capital and social capital are complementary. Entrepreneurial institutions and environment is also one of the most important determinants of innovative activities. Aghion and Bircan (2017) underlined that entrepreneurs' incentive to investment depend on economic policies and institutions. Well-functioning economic institutions lead more fair entrepreneurial environment to promote innovation-based growth in community level. Constructing a strong social capital and well-formed economic institutions is long term policy areas and requires high level of investments.

Creation of suitable competitive environment for companies and Small and Medium Sized Enterprises (SMEs) is an indirect way of supporting innovation. Financing national research and stimulating individual investment of R&D is direct way to affect innovation performances of firms. Economic policy instruments that aim to change economic structure for innovation takes long time. In this process, states imply some support policies that help firms in their R&D projects.

Laincz (2009), criticized early creative destruction models of growth that state R&D subsidies benefit potential entrants of markets with zero market share. The theoretical and empirical findings of Laincz (2009), indicate that public R&D subsidies benefits incumbent firms and increase value of these firms through directly cost reduction and rank stability effect. This study displays that market leadership change occur in 21.9% of the periods with subsidies while this change occurs in 32.9% of the periods without R&D subsidies. As a contribution to the idea above, Acemoğlu et. Al. (2013) built a micro-founded model on entrant and incumbent firms that are categorized as low type and high type with respect to productivity in innovation. They underlined the significance of supporting new entrants and criticized direct support of low-type incumbent.

In addition, Xiafei, Zhiying and Chaoliang (2017) made an empirical analysis on R&D efficiency across countries. The most important finding of this empirical analysis is that increasing R&D expenditure may not be the optimal policy instrument. To promote innovative activity in an economy, other incentive policy instruments can be pursued such that state-owned enterprises, staff training, infrastructure construction and more effective legal and financial system etc. Terzić (2017) studied the various categories of innovation that play different roles in development. This empirical research was conducted in selected developing economies from Europe. The positive and significant effect of R&D expenditure as percent of GDP on global innovation index (GII) and GDP per capita was found. According to the calculated effects of R&D expenditure on economic growth, it can be argued that governments should constructed appropriate research systems, better business conditions for entrepreneurship for development goals.

6. CONCLUSION

The motivation of this study is to grasp the reasons of low R&D expenditures in developing economies in spite of many studies that focus on the positive relationship between R&D intensity and economic development. The reasons behind this phenomenon is not just limited financial resources in these countries as compared to developed ones. The share of R&D expenditures as percent of GDP is a good indicator for this inference. While high income countries invest in R&D 2.5% of their GDP, upper middle-income and middle-income countries invest 1.8 and 1.4% of their GDP in R&D respectively (World development indicators by Worlbank open data). Firms are the main decision makers that affect R&D expenditure and innovation level of countries.

Therefore, this paper developed a theoretical model that shows the determinants of R&D decisions of firms. Our model brought a novelty to patent race literature by differentiating returns of R&D and the probability of early success for incumbent and entrant firms. The incumbent firms are technological leaders in their markets. At the first stage, all firms decide whether to enter patent race or not. Staying out of the patent race provides the chance of obtaining the existing incumbents' technology to a potential entrant. If one of the incumbents succeeds in R&D and the entrant firm has enough resources to imitate old technology of successful incumbent, entrant firm can make positive profits in this market. This positive profit affects the payoffs of patent race through changes in market structure and competition.

In the second stage, firms that entered into the patent race makes R&D investments for early success. The expected values of the patent race are determined by the strategy profiles of firms and R&D investment level. However, the return of R&D investments on time for early success is different for the incumbents and the entrant.

We calibrated our model by choosing two leader firms from the mobile phone market; Apple and Samsung. In 2011, those firms share 38 % of total mobile phone sector equally and produce the highest quality and almost identical products in their market. We estimated an inverse demand function for those two firms on the assumption that

We interpret Huawei as a new entrant firm in 2011 and assume that it made an optimal R&D investment by 3,668 million USD. In 2011, Samsung's R&D expenditure can be considered as an optimal investment for an incumbent firm. Under these assumptions, we computed the different parameters of a linear hazard rate function for entrant and incumbent firms. We found that there is a significant difference between incumbent and entrant firms in terms of R&D expenditure return on time of early success.

Based upon these estimated parameters, we computed the difference between expected values of entrant firm in cases that waiting for end of patent race between incumbent firms (case B) and to enter patent race (case A). The difference between case B and case A is positive and reduces as innovation becomes more drastic that cause more decreases in production cost. Knowledge accumulation, learning by doing or any other form of increasing returns to scale also affect the hazard rate function parameter of firms. If the entrant firm can achieve a better efficiency level in R&D processes and can increase hazard rate function parameter, then case A turns out to be more profitable.

REFERENCES

Acemoğlu, Daron, Dan Cao . 2010. Innovation By Entrants and Incumbents. NBER Working Paper 16411 .

Acemoğlu, Daron, Ufuk Akçiğit, Harun Alp, Nicholas Bloom, William R. Kerr .2013. Innovation, Reallocation and Growth. NBER Working Paper No. 18993 .

Acemoğlu, Daron, Gino Gancia, Fabrizio Zilibotti. 2010. Competing Engines of Growth: Innovation and Standardization. Massachusetts Institute of Technology Department of Economics Working Paper Series.

Aghion , Philippe, Cagatay Bircan. 2017. The Middle-Income Trap from a Schumpeterian Perspective. ADBI Working Paper 521.

Aghion , Philippe, Peter Howwit. 1992. A Model of Growth Through Creative Destruction. **Econometrica**, Vol. 60, No. 2, 323-351.

Akçomak, Semih, Bas ter Weel. 2009. Social Capital, Innovation and Growth: Evidence From Europe. **European Economic Review**, Vol 53, 544-567.

Analyze the future. (2018, December 15). Retrieved from Idc corporate: https://www.idc.com

Annual Reports. (2019, January 1). Retrieved from Huawei: https://www.huawei.com/en/press-events/annual-report

Arrow, Kenneth. 1962. Economic Welfare and the Allocation of Resources for Innovation. **The Rate and Direction of Inventive Activity: Economic and Social Factors**. Princeton University Press.

Batabyal, Amitrajeet, Seung Jick Yoo. 2018. Schumpeterian Creative Class Competition, Innovation Policy and Regional Economic Growth. **International Review of Economics and Finance**, 86-97.

Buddelmeyer , Hielke, Paul H. Jensen, Elizabeth Webster. 2006. Innovation and the Determinants of Firm Survival. IZA Discussion Paper No. 2386.

Cayseele, Patrick Van. 1998. Market Structure And Innovation: A Survey Of The Last Twenty Years. **De Economist,** Vol 146, 391–417.

Chang, Ha Joon. 2001. Intellectual Property Rights and Economic Development: Historical lessons and emerging issues. **Journal of Human Development,** Vol 2, 287-309.

_______. 2008. **Bad Samaritans: The Myth of Free Trade and the Secret History of Capitalism.** New York : Bloomsbury Press.

Dasgupta , Partha, Joseph Stiglitz. 1980. Uncertainty, industrial structure, and the speed of R&D. **The Bell Journal of Economics,** Vol. 11, No. 1 , 1-28.

Financial information: Earnings Releases and 10-K Annual Reports. (2019, January 1). Retrieved from Apple investor relations: https://investor.apple.com/investor-relations/financial-information/default.aspx

Freeman, Chris, Luc Soete. 1997. **The Economics of Industrial Innovation.** Pinter.

Futia, Carl. 1980. Schumpeterian Competition. **The Quarterly Journal Of Economics,** Vol. 94, issue 4, 675-695.

Gilbert , Richard, David M. Newbery. 1984. Preemptive Patenting and the Persistence of Monopoly: Reply . **The American Economic Review**, Vol. 74, No. 1, 251-253.

Glass, Amy, Kamal Saggi. 1998. International technology transfer and the technology gap. **Journal of Development Economics**,Vol. 55, Issue 2, 369-398.

Glass, Amy, Xiaodong Wu. 2007. Intellectual Property Rights and Quality Improvements. **Journal of development economics,** Vol 82, 393-415.

Gottschalk , Sandra, Nobert Janz . 2001. Innovation Dynamics and Endogenous Market Structure Econometric Results from Aggregated Survey Data. ZEW Discussion Paper. 01-39.

Grossman, Gene, Elhanan Helpman. 1991a. **Innovation and Growth In The Gloabl Economy.** Cambridge: MA: The MIT Press.

Grossman, Gene, Elhanan Helpman. 1991b. Quality Ladders in the Theory of Growth. **The Review of Economic Studies,** 43-61.

Investor Relations. (2019, January 1). Retrieved from Samsung: https://www.samsung.com/global/ir/reports-disclosures/sustainability-reports/

Laincz, Christopher. 2009. R&D subsidies in a model of growth with dynamic market structure. **Journal of Evolutionary Economics.** c. 19, 643 - 673.

Loury , Glenn. 1979. Market Structure and Innovation. **The Quarterly Journal of Economics.** Vol. 93, No. 3 , 395-410.

Lucas, Robert. 1988. On The Mechanics Of Economic Development. **Journal of Monetary Economics,** Vol 22, 3-42.

Mankiw, N. Gregory. 2012. **Principles of microeconomics.** Mason, OH: South-Western Cengage Learning.

Mazzucato, Mariana. 2000. **Firm Size, Innovation and Market Structure: The Evolution of Industry Concentration and Instability.** Cheltenham: Edward Elgar Pub.

_______. 2014. **The entrepreneurial state : debunking public vs. private sector myths.** London and New York: Anthem Press.

Mukoyama, Toshihiko. 2003. Innovation, imitation, and growth with cumulative technology. **Journal of Monetary Economics,** Vol 50 , 361–380.

Phillips , Almarin. 1966. Patents, Potential Competition, and Technical Progress . The **American Economic Review,** Vol. 56, No. 1/2 , 301-310 .

Ramsey, Frank. 1928. A Mathematical Theory of Saving. **The Economic Journal,** Vol. 38, No. 152 , 543-559.

Reinganum, Jennifer F. 1989. The Timing of Innovation: Research, Development, and Diffusion. in R. Schmalensee, & R. Willig, **Handbook of Industrial Organization.** Elsevier Science Publisher B. V.

Romer, Paul. 1986. Increasing Returns and Long-Run Growth . **The Journal of Political Economy**, Vol. 94, No. 5 , 1002-1037.

Rosen , Richard J. 1991. Research and Development with Asymmetric Firm Sizes. **The RAND Journal of Economics**, Vol. 22, No. 3 , 411-429.

Schumpeter, Joseph. 1942. **Capitalism, socialism, and democracy.** New York ; London : Harper & Brothers.

Shefer, Daniel, Frenkel, Amnon. 2005. R&D, firm size and innovation: an empirical analysis. **Technovation**, 25-32.

Solow, Robert. 1956. A Contribution to the Theory of Economic Growth . **The Quarterly Journal of Economics,** Vol. 70, No. 1 , 65-94 .

Stiglitz, Joseph. 1998. Toward New Paradigm for Development. **UN Conference on Trade and Development.**

________. 2015. Leaders and Followers: Perspective on the Nordic Model and the Economics of Innovation. **Joural of Public Economics 127**, 3-16.

Swan, Trewor. 1956. Economic growth and capital accumulation. **Economic Record,** 334-361.

Terzić, Lejla. 2017. The role of innovation in fostering competitiveness and economic growth: evidence from developing economies. **Comparative Economic Research,** Vol. 21, N. 4,.

Thompson, Maria. 2018. Social capital, innovation and economic growth. **Journal of Behavioral and Experimental Economics**, 46-52.

Tirole, Jean. 1988. **The Theory of Industrial Organization. London**: The MIT Press.

Worldbank Open Data. (2019, February 15). Retrieved from Worldbank: https://data.worldbank.org/

Xiafei , Chen, Zhiying Liu, Chaoliang" Ma. 2017. Chinese innovation-driving factors: regional structure, innovation effect, and economic developmentempirical research based on panel data. **The Annals of Regional Science**, Vol. 59, Issue 1. 43–68.

CURRICULUM VITAE

NURTEN KAYNARCA
(08.01.1994)
E-mail: kaynarcanurten@gmail.com

EDUCATION INFORMATION

Yıldız Technical University (MSc)
Graduate School Of Socıal Sciences, Economics, GPA: 3.29/4, 2016 - 2019

İstanbul University (BSc)
Faculty of Economics, Economics, GPA: 3.24/4 (Honour Student), 2011–2016

JOB EXPERIENCE

Analyst- Finance Office of the Turkish Presidency, Ankara
December 2018 – Present

Research Assistant – Bartin University, Bartin
May 2018 – Present

Research Assistant – Istinye University, Istanbul
April 2017 – April 2018

FOREIGN LANGUAGE: English (Advanced)

COMPUTER SKILLS AND PROGRAMS: MS Office, Stata, Mathematica, Spss, E-views

EXAMINATIONS:

ALES: 84 YÖKDİL: 93,75

CONFERENCE TALKS AND SEMINARS

- Innovation As A Tool Of Development: A Patent Race Approach, V. Yıldız Uluslararası Sosyal Bilimler Kongresi, December 2018