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The Impact of Patents on Research & Development Expenditure as a Percentage of Gross Domestic Product: A Case in the U.S. and EU Economies

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The Impact of Patents on Research & Development Expenditure as a Percentage of Gross Domestic Product. A Case in the U.S. and EU economies.

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Abstract:

This paper examines the recent upward trend of patent applications and its impact on Research and Development Expenditure in the U.S. and the EU. Opening with the decline in total factor productivity in the United States, the paper focuses on the decline by analyzing the effect that patents have on research and development expenditure, taking firm size, government subsidization, and historical financial performance, into account. Patents were found to have an increasing effect on research and development expenditure decreasing rate.

I. Introduction:

This paper's goal is to investigate the impact, if any, that patents have on research and development expenditure, using the United States and European Union as the samples. The time will be from the mid-1990s to the mid-2010s. Since the late twentieth century, the United States has been facing a decline in growth of total factor productivity. As economists, we view productivity as a vital component to a growing economy. Any productivity lost that could have been gained instead can be considered an opportunity cost. For firms to stay competitive, they must be productive, for goods to stay at the equilibrium price, goods and services must be produced at equilibrium level which requires labor and capital. That is not to say productivity is on the decline, but that productivity is increasing but at a decreasing rate. For the future this means we can only expect marginal gains in growth in all sectors. While this decline in growth has occurred, the number of patents have been exponentially increasing since the 1970s, simultaneously, R&D expenditure has oscillated around the 2.5 percent mark (Boldrin, Levine, 2013, p. 2). It should be a concern to regulators that patent litigations could create potential opportunity costs that could put the economy at a disadvantage.

Looking at the historical purpose for patents. Patents of the past protected the innovator's financial interest by restricting would-be innovators from copying their design or 'art'. A patent, also known as intellectual property rights, is no different from a property right for a house. However, like property rights, patents also suffer from costly litigation disputes. However, unlike a house, patents can greatly affect innovation in an economy for better or worse. Patents found immense popularity with the "third industrial revolution" (Gordon, 2016, p. 578) during the 1990s, also known as the internet boom. It was also at this period that the growth in total factor productivity, a measurement for determining how efficiently inputs are utilized in production, was at its lowest in comparison to its historical counterparts.

The purpose of this paper is to analyze the relationship, if any, between the exponential rise of patents and the oscillating nature of R&D expenditure present in both the U.S. and EU. Data on patent applications, patents granted, R&D expenditure, subsidization, firm size distribution, and historical financial performance, is gathered. A double-log function will specify the regression model since it is expected that the relationship between patents and R&D expenditure is non-linear.

The contributions of this work are providing an econometric model to Boldrin and Levine's (2013) opening statement concerning patents and R&D expenditure. Whereas a linear model is only concerned about constant slopes, a double-log model will show changing elasticities in the slopes. This allows us to see whether, if statistically significant, patents have an increasing effect on R&D expenditure at an increasing or decreasing rate or a decreasing effect at a decreasing rate (Sokolov-Mladenović, Cvetanović, and Mladenović, p. 13, 2016).

Patents were found to have an increasing effect on R&D expenditure at a decreasing contrary to the expectation that patents would simply be negative. The magnitude of the effect increased as the firm size variable increased. The firm size variable itself was the most varied in terms of coefficients. Although both were relatively unaffected when placed under a different patent variable, the order of magnitude was the most surprising. Subsidization fell out of expectations possibly to due to the 'relabeling' issue. Historical financial performance also fell out of expectations possibly due to the fact that its theory is based on Booth, Junttila, Kallunki, Rahiala and Sahlström's (2006) linear relationship expectation between equity performance and R&D investments.

Section II reviews the literature. Section III presents the analytical framework. Section IV lists the data and variables used. Section V specifies the final econometric model. Section VI shows the sample regression and discussion of results. Section VII concludes with a discussion on policy implication, limitations of research, relation to the literature, and future research possibilities.

II. Literature Review:

To frame the main topic, I will be looking at the patent systems of the US and the EU and seeing how the relationship between patents and research and development expenditure in the US and the EU compares to one another.

The comparison of the U.S. and EU would help to better understand the relationship of patents, R&D, innovation, and then hopefully economic growth. Despite the EU being a representative entity of its members rather than a single country like the US, the size and significance and exposure to economic shocks will allow me to better compare the two entities than say using a much smaller and less relevant entity to compare to the US. In addition, the US and EU both have well-fleshed out patent systems that aren't hampered by the issues faced by developing countries, this allows the two entities to be more comparable.

However, property and patents only *potentially* provide incentives. Bessen & Meurer (2008) find that property rights can fail when their *validity* is uncertain. Using the transition from Mexican to American rule in California during the nineteenth century, as an example, there was a clouded validity of land titles under Spanish and Mexican Rule. This uncertainty led to squatting and decline in agricultural productivity. Property rights can fail when rights are so fragmented that costs of acquiring & negotiating the rights necessary to make an investment becomes cost-prohibitive. This was the case in Russian retail establishments in the USSR's transition to a private economy. Ownership rights were granted to many interested parties, making it difficult for any one party to acquire the necessary ownership rights to operate a store. Stores were often out of business while street vendors conducted trade nearby. Property rights can fail when boundary information is not made publicly accessible. In developing countries people were discouraged from recording their property right boundaries, due to cumbersome regulation, which limited their ability to trade property or use it as collateral for obtaining loans. Finally, property rights can fail when there are no clear and predictable boundaries of the rights. This problem is common with property extracted from nature, such as mineral extraction rights. Minerals beneath earth twist and turn in unpredictable ways. Such an unpredictable boundary led to a violent struggle between rival claimants in Butte, Montana.

While these examples are wide in scope in terms of time and international evidence, it emphasizes the importance of proper implementation of property rights, including patents. Economic effectiveness of any property systems depends not just on what it protects, but also on the institutions, regulations, laws, and norms that implement the property systems. Subsequently, the similarity between patent law and law of tangible property can obscure crucial differences in economic performance indicators because these similarities are implemented differently. A tangible property law might not work as well as patents if patent law is not implemented effectively.

Background

As economists, we view innovation, in the form of new products and processes as public goods. This means inventors and authors cannot prevent others from appropriating or using their inventions without the intervention of the legal system. It was discovered that an imitator's cost are approximately 65 percent of the original innovator's cost. Most of the results produced by R&D are already in the hands of imitators within 12 to 18 months of the original invention (Glick, Hoffman, Reyman, p.63, 2003). The goal of intellectual property law is the optimal subtraction of total social cost of innovation subtracted from total social benefit. However, issues in the apparent trade-off between IP laws and incentives for dynamic efficiency and incentives for static efficiency.

For reference, dynamic efficiency refers to the increase in consumer welfare from cost-reducing processes and new products. Static efficiency refers to the increased benefit that consumers obtain from lower prices and increased input (Glick, Hoffman, Reyman, p. 64, 2003). In terms of total factor productivity, dynamic efficiency and static efficiency will influence its rate of growth over time.

Benefits from innovation include lower factor costs overall and better products. However, there is a twofold cost to this trade-off. The opportunity cost that innovation consumes, through R&D expenditure, on resources that could be put to other uses, and the reduction of static efficiency due to the exclusionary rights that IP laws grant, meaning consumers pay higher prices and the market has less output than the equilibrium. Nordhaus (1969), one of the first economist to address this trade-off, discovered that as the amount of cost reduction from innovation from longer patent length increases, society waits longer for the full benefits of the innovation to materialize. Simultaneously, growth profits earned by monopolies decrease heavily, resulting in less incentivization to innovate. In my paper, I will not be using patent length, but rather the generalized form of patent applications to capture the macroscopic effect of patents on R&D expenditure.

Innovation benefits the economy and the community by creating new and improved means of producing goods and services to satisfy social needs. For example, an innovation into a vaccine for a deadly virus will substantially reduce child mortality in poverty stricken countries, thereby increasing the chances of a healthier workforce. However, the United States has experienced 1.2 percent annual growth in total factor productivity between the period of 1970 to 1979, while in the periods 1990 to 1999 and 2000 to 2009 it has been below 1 percent. Meanwhile, US research and development expenditure has fluctuated around 2.5 percent of GDP. Simultaneously, the number of patents issued more than quadrupled (Boldrin, Levine, 2013, p. 2). Boldrin and Levine (2013) assert that patents do not help with innovation, however they do not establish any empirical relationship between patents and research & expenditure, which the latter is a vital component to inventing and innovating. The empirical relationship is what this paper sets out to do.

Relationship between Patents and Research and Development

Chaudhuri find that after the introduction of TRIPS, (Agreement on Trade-Related Aspects of Intellectual Property Rights), the large Indian pharmaceutical companies who are significant R&D spenders have been focusing on countries with more lucrative markets such as the United States. In this regard, the primary incentive to invest in R&D was not due to the TRIPS agreements but the already established product patent regimes in developed countries which TRIPS did not apply to. TRIPS accelerated the R&D activities due to restrictions placed by TRIPS on domestic opportunities, but in the absence of TRIPS R&D activities would still have been undertaken. Furthermore, with larger domestic operations in the absence of TRIPS, Indian pharmaceuticals would have had access to larger pools of technical resources. TRIPS introduced a framework for intellectual property rights to member countries. Patenting by Indian pharmaceuticals also rose significantly. Pharmaceutical R&D activities became diversified but pharmaceuticals did not create new innovative products. The only noticeable change was the ability for Indian companies to develop generics, an ability that was already acquired and improved before TRIPS.

Despite the lack of innovative pharmaceutical products, the impact of TRIPS is unlikely to have a negative impact on overall productivity growth. Developing countries tend to have the largest market for new drugs (Chaudhuri, 2007, p.17) which generic companies can take advantage of. Generic companies are legally entitled to continue developing processes for drugs that have been innovated from abroad and supplying these at lower prices locally and to other developing markets. In the case of antiretroviral drugs (ARVs), the price of the originator company exceeded $10,000 per person per year, far beyond the reach of most people in developing countries. However, when Indian generic companies acquired and developed the processes for ARVs the prices were improved substantially due to competition among the generic companies. Prices were reduced to less than $100 per year from India. (Chaudhuri, 2007, p.18). The example of the economic effects the TRIPS agreement had on Indian pharmaceuticals is one of the reasons why this paper is comparing the US to the EU. The two are highly developed economies that follow their own well-established patent protocols. The TRIPS agreement modified the R&D activities of Indian pharmaceuticals to focus on capturing the generics market meaning there is potentially less incentivization to innovate new drugs.

However, the US and the EU markets is saturated with generics meaning there is still a strong incentive to innovate.

The private sector continues to contribute the majority share of research funds. In 2009, private R&D expenditure was twice the size of government sponsored R&D (Clancy and Moschini, p. 3, 2013). Such a large quantity of private R&D must overcome the problems associated with the private provision of knowledge, which could generally be a public good. One solution to overcome the acquisition of a public good in a market setting can be seen in legally sanctioned intellectual property rights (IPRs). IPRs can take the form of patents, copyrights, trademarks, and trade secrets. The privatization of knowledge brought about by IPRs brings out some unintended consequences and side effects which include social costs that run against the supposed positive incentive effects that patents provide

Patents grant individuals or groups the right to exclude others from making, using, or selling patented ideas and techniques. Thus, patents endow inventors with property rights to their knowledge and ideas, thereby affecting the exclusivity of the otherwise public good. Patents are limited in time (the period of protection) and scope (the parameters granted by the patent). For the purposes of this paper, these factors will be encompassed by an aggregate total number of patent applications and patents granted. This will make the effects of patents on R&D expenditure generalized but simpler to understand.

The extent to that patents provide an incentive to innovate depends on patent length and on the scope of its intellectual and exclusionary rights, the patent's breadth. The patent's breadth directly influences the size of the original innovator's profit flow, and the deadweight welfare loss *L*. Narrow patents (i.e. patents that do not have significant breadth), which easy to imitate, may not provide sufficient levels of providing incentives to innovators. However, broader patents may bring upon deadweight losses due to an excessive monopoly distortion and a decrease in the rate of technical progress, since future innovation are faced with obstacles raised by previous innovators (Encauoua, 2003, p.2). Although it makes logical sense to include patent breadth and depth into my patent variable, it is currently beyond the scope of this paper which is about analyzing the macro effect of patents on R&D expenditure. Encauoua (2003) developed patent variables based on length and breadth due to the fact it is micro focused variable. My paper aims to find the net effect that patents have on R&D expenditure as a percentage of GDP. To consider the dozens of industry's hundreds of thousands of patents to understand the dynamics of R&D and patents is simply beyond my current technical ability.

Extending the point about incentives, Hunt (2006) presents a simple model that explores the relationship between the incentive to invent, the requirement of R&D expenditure, and the incentive to obtain patents. Treating the two incentives as separate decisions, Hunt derives that patents and R&D to be substitute inputs in the production of firm profits. Hunt discovers firms that typically do a lot of R&D also tend to patent more. Ordinarily, reducing the cost of R&D, or of patenting, will stimulate additional R&D expenditure. However, there is a point at which patents reduce R&D expenditure. Every firm is concerned with its rival's patent strategies and the rents its rival could incur if it infringes upon the rival's patents. Compiled with the incremental reductions in the cost of obtaining patents, the likelihood of infringement increases. This does not mean R&D investment is eliminated, however, it is reduced so less innovation would occur. The firm could potentially lose out on any productivity enhancing inventions (Hunt, p.1, 2006). This is crucial as it explains firm behavior in a market filled with incomplete information about patents. Firms would react differently if they had perfect information on their competitor's patents. This adds to the difficulty of creating a reliable patent variable. By using patent application data, which I have easier access to than individual patents, I will be able to capture the aggregate effect of multiple industries' decision making.

Relationship between Research and Development and Innovation

With innovation, research & development, and patents all connected, this paper will be focusing on the relationship between patents and R&D. Innovation, the byproduct of the R&D and patents, is also a key component to economic growth. By keeping the focus on R&D, we can isolate the possible relationship between patents and research and development.

Boldrin & Levine begin with the disconnect between patent growth and productivity growth known as the "patent puzzle". In recent decades as patent protection was progressively strengthened we did not observe an innovative explosion. Per the Bureau of Labor Statistics annual growth in total factor productivity in 1970-1979 was about 1.2 percent, while in 1990-1999 and 2000-2009 it was less than 1 percent. Despite increase in number of patents issued, the U.S. economy has not exhibited any similar upward trend in technological progress nor a similar increase in R&D expenditure. In the same period, R&D expenditure has been oscillating around 2.5% of GDP. The recent explosion in patents did not come from new industries such as biotechnology and software.

The first half of the literature attempts to answer the question of whether patents encourage productivity growth. The authors conducted a meta-analysis that examined whether patent introducing or strengthening patent protection lead to greater innovation. Their studies found little to no evidence that strengthening patent systems increased innovation. They found countries that start off with weak intellectual property regimes have increased flow of foreign direct investment to sectors where patents are commonly found. Countries like the U.S. and EU are not as reliant on foreign direct investment, allowing me to isolate the effects of patent protection on R&D expenditure.

Boldrin and Levine (2004) attempt to debunk common proponents for patent protection. One proponent is the notion that patents are a substitute for socially costly trade secrecy and improve communication about ideas (Boldrin and Levine 2004; Ponce 2007). While studies of the usefulness of information disclosure in patent litigation are not widely available, according to sworn testimony by Google's chief of Android development during Oracle vs. Google, engineers that developed Google's Android were unaware of Oracle's patents and so were not helped by the patents (Niccolai 2012). A Microsoft developer reflects on one of its many practices to "never search, view, or speculate about patents". The legal jargon was indecipherable by anyone except a seasoned patent attorney. Ignorance was the preferred method of innovation.

Boldrin and Levine comment on a separate study done by Anwar and Evanson. The difference in this paper and mine is that I will be comparing two roughly similar large economies. They illustrate of the issues that arise from studies on patents and innovation. Based on data for 31 countries between the period of 1981-1990, they find support for the correlation that higher patent protection leads to higher R&D spending as a percentage of GDP. However, the opposite was also plausible. Countries with larger markets can easily shoulder the fixed costs of innovation.

Anwar and Evanson compares countries with relatively small economies, very little patent litigation, and low R&D expenditure with countries with relatively larger economies, significantly greater patent litigation, and higher R&D expenditure. In summary, their findings show that strengthening intellectual property protection increase R&D expenditure up until a certain point that is the gains to R&D expenditure falls. Countries on the lower levels of GDP have their R&D expenditure primarily influenced by foreign direct investment even though these countries have little to no patent litigation. Countries with higher levels of GDP don't have the same issue, meaning R&D expenditure is not likely to be affected by foreign direct investment. Further justifying my selection for the U.S. and EU as my samples.

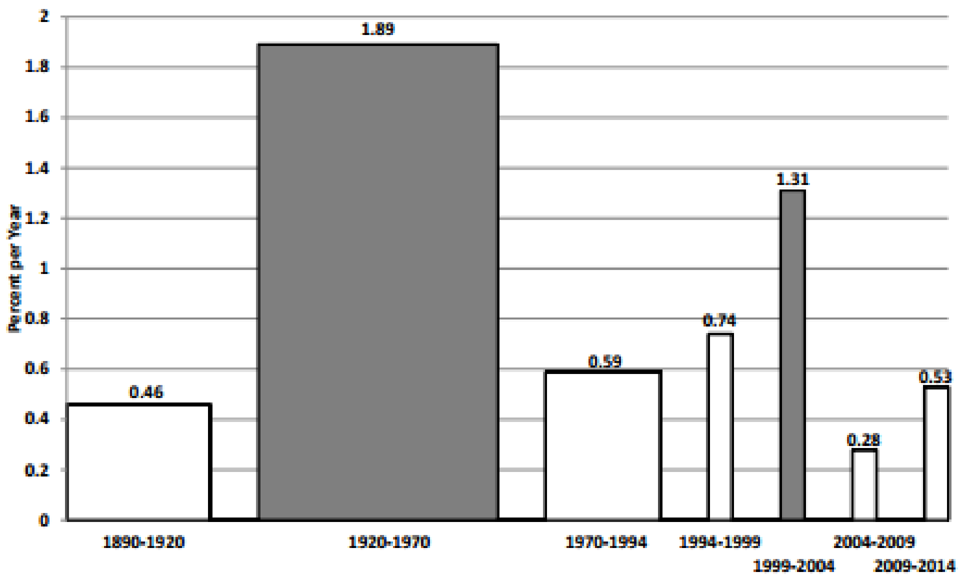

Figure 1. Annualized Growth Rates of Total Factor Productivity: 1890-2014. This figure illustrates the diminishing growth of total factor productivity from Gordon (2016)

Looking closely at the behavior of total factor productivity (TFP) growth shown by the vertical bars in figure 1 for 1890-1920, 1920-1970, and three subperiods since 1970. The first subperiod, 1970-94, shows only 0.59 percent TFP growth per year, less than a third of the 1.89 percent growth achieved in the 1920-1970 period. TFP growth was faster in 199-2004 than the other two subperiods post-1970.

The contrast between the white and grey bars is an interpretation of the significant rise in the level of TFP because of the implementation and extension of the pioneering inventions associated with the Second Industrial Revolution of the nineteenth century. The 1999-2004 TFP annual growth reflects the contribution of the Third Industrial Revolution, associated with computers and digitalization. Simply looking at the differences in contributions to TFP growth, the Second and Third Industrial Revolutions were quite different. The second industrial revolution's TFP growth lasted for half a century, while the third industrial revolution had a shorter-lived and a smaller magnitude in TFP growth.

The third industrial revolution saw the marriage of communication and computers. In the short interval between 1993 and 1998, the standalone computer was linked to the real world through the internet. The market for internet services surged. The world became more integrated through powerful software and connectivity. Gordon notes that the effects were limited in the sphere in of human activity in contrast to the effects of the second industrial revolution which changed everything such as the automobile, household appliances, and medicine. About Robert Solow's 1987 computer paradox, "You can see the computer age everywhere but in the productivity but in the productivity statistics", Gordon simplifies this to the fact that we don't fully utilize the innovations of the third industrial revolution the same way we used the innovations of the second industrial revolution. In other words, we don't eat computers or wear or drive to work in them or let them cut our hair. The functions of our homes remain the same, the functions of our automobiles remain the same albeit with more convenience and safety (Gordon, 2016, p. 578).

While Gordon presents a solid reason behind the suspected lack of TFP Growth in post-1970s subperiods. I believe Gordon is too hasty in his conclusion that IT is not a significant contributor to growth. Historically speaking, for every innovation, such as the steam engine and electricity, there has been an initial lag in fully implementing technology into society. After time passes, the dividends of an innovation turned productivity-enhancing technology are reaped slowly, and over time the new technologies diffuse into common use. With the IT industry being amongst the most influential innovator during the late 20th century, no other technology in United States history has faced anything like the broad industry opposition to software patents that arose during the 1960s to the mid-1990s (Bessen & Meurer, 2008, p.189).

Campbell-Kelly, a computer science professor, argues that software patents are no different from other technologies, meaning the patent system will adapt to the demands of software patents over time. However, during the 1994-2004 period, software patents were among the highest rates of litigation and high rates of clam-construction review on appeal. While the tangible property rights revolve around *concrete* technology, it can be argued that software patents revolve around *abstract* technology. Referring to our patent viability laws, abstract patent claims can violate the "rule of first possession", thereby allowing patent holders to lay claim to a broad range of technology that have yet to be invented. Abstract patents have unclear boundaries and can give rise to opportunistic litigation. It can be implied that there is something crucially different about software patents (Bessen & Meurer, 2008, p.188).

This is not to say software publishers haven't flourished despite the growth of software patents, in fact it is the opposite. Preliminary studies show that although there is evidence of some of negative effects of patents within the software industry, they have not been serious or widespread. However, the general concern is over the software patents not the software industry. The distinction is important because almost non-software industry firms obtain the software patents such as electronics, telecommunications, and computer industries, while the software-publishing industry only obtains 5 percent of all software patents granted (Bessen & Meurer, 2008, p.190).

The incentive to innovate certainly does exist for most industries. One incentive is the prospect of becoming a monopoly as a reward for innovation. In terms of innovation, monopolist power over an industry can bring the many consequences we associate with monopoly power. While the positive impact of patents is the partial equilibrium effect of increasing profits to the innovator at the monopolistic level, the negative effect is the subtler general equilibrium of a reduction in everyone else's ability to compete while promoting the incentive to engage in costly patent litigation lobbying efforts. This creates social costs and opportunity costs since potential R&D investment efforts are wasted away in litigation. Earlier on in my research I considered competition as an independent variable, since monopolies would use patents to secure their rents. I would have used to Herfindahl-Hirschman Index to compare five industries that contributed to 80 percent of R&D expenditure. However, industry data was limited by its time span which would require a massive amount of numbers to be generated to fill in the missing data. This would have likely skewed my data, so I avoided this variable for the time being.

A successful and useful innovation will most of the time drive labor productivity growth. Therefore, it's important to understand the relationship between patents and R&D expenditure is to gain insight in the potential economic costs or benefits that patents may have total factor productivity.

<u>Relationship between Research & Development Expenditure and Total Factor Productivity</u>

Research and development is often said and done, but what does it exactly mean? For our purposes, in this paper, we use the Bureau of Labor Statistic's definition (BLS) of R&D. Two types exist, private R&D refers to R&D funded by private firms, and public R&D refers to researched financed or conducted by government or nonprofit institutions such as colleges, universities, or foundations. However, for my purposes we will see both types of R&D as a percentage of GDP.

Innovation and knowledge are examples of a public good because of its spillover effects to other potential users since new technology is typically not confined to its discoverer. For example, a new drug developed by a pharmaceutical for a certain disease has its inherent benefits, but a competitor can study the previous iteration and build on that foundation of knowledge to develop an even better drug. The pioneering firm earns returns by selling its initial product. However, the pioneering firm’s research generates further benefits by making the following firm’s research feasible (Bureau of Labor Statistics, 2012).

There is a close relationship between R&D expenditure and total factor productivity. R&D expenditure is heavily concentrated in manufacturing, a sector of the economy that is declining (Clark, 2016, p.2). By contrast, the services industry has very little R&D expenditure. As of 2015, the service sector accounts for around 80 percent of US economic output, manufacturing sits at 12 percent of the economy. More than 80 percent of all R&D lies in three sectors of the economy, information and electronics manufacture, medical substances and devices, and transportation equipment, produce together less than 5 percent of value added or GDP (Clark, 2016, p. 2).

The Bureau of Economic Analysis reported approximates of how much R&D expenditure by private firms contributes to productivity growth. Combined with the BLS estimates of productivity spillovers, we can assess the impact of private R&D on productivity growth. There is evidence that R&D is a strong influencer on productivity growth (BLS, 1989). Studies have found that the returns of R&D are extremely high and that R&D is strongest and most consistent influence on factor productivity growth. R&D provides both direct productivity benefits to industries conducting research, such as computer or aircraft manufacturers, and indirect benefits to industries further along the chain of production such as when financial institutions take advantage of new computing technology (Sveikauskas, 1986, p.1). He notes that while R&D has received much attention, it only represents a portion of the social and individual factors related to innovation. Other factors such managerial and organizational quality, the integration of the industrial relations systems, factors that are difficult to quantify for the purposes of this paper are all important components for technological advancement. These qualitative factors, however, would make a logical extension for future research.

With this established relationship between R&D expenditure and productivity in mind, the paper will primarily focus on the potential relationship between patents and R&D expenditure. The motivation behind such protection revolves around the idea that without property rights on ideas, the free market might underinvest, directly undermining research & development expenditure relative to the socially optimal level, in the costly development of new technologies (Gilchrist, 2016, p.1).

III. Analytical Framework:

Economic theory behind Research and Development Expenditure and Patents

Alan Greenspan, former chairman of the Federal Reserve commented that intellectual property has received a lot more attention than in recent decades because ideas and innovation have become important economic resources. Property rights on ideas have outgrown the demand for property rights on land, energy, and raw materials. At present, publicly traded companies in the U.S. have three-quarters of value placed in intangible assets, up from 40 percent from 1980. The product of the U.S. economy has become predominately conceptual. Intellectual property rights form parts of these conceptual assets (Bessen and Meurer, p. 112, 2008).

In its relation to R&D expenditure, patents serve as the financial reward for anyone who is willing to incur R&D costs. Recall that the product of R&D is knowledge which is a non-rival good, meaning that the use of knowledge by one individual does not limit the ability of others to use it. Intuitively, it is possible to contextualize R&D expenditures in a competitive market economy. Assuming knowledge is subject to scarcity, like all other limited resources, the market price of knowledge is assumed to reflect the efficient allocation of resources by equating the marginal social cost of the good with its marginal social benefit. As a non-rival good, knowledge can be consumed at zero marginal social cost. With the marginal social cost equal to zero, we would assume that people would consume knowledge at the efficient level where marginal benefit is zero, the optimal level of use, thus knowledge must be distributed freely at a zero price (Parker, p. 4, 2012).

Clearly this goes against the incentive to invest since there would be no financial reward to reap from incurring R&D costs. Patents and copyright laws grant monopoly rights on intellectual-property. The inventor of said knowledge would be inclined to charge a royalty for the license to use knowledge or earn monopoly profits. However, the following paragraph will illustrate why charging a positive price for the use of a non-rival good can lead to inefficiency. If individuals are required to pay to use knowledge, but the marginal social cost is zero, knowledge will be used at a lower-than-optimal level. Therefore, intellectual-property rights work as intended, to protect an inventor's financial interests and those to follow, but at the same time create another negative externality by creating market inefficiencies.

To illustrate the costs and benefits behind the incentives of patents, consider this the market for a new product that can be produced at a constant marginal cost $c < \bar{p}$ (figure 1) The downward sloping demand curve D(p) represents the diminishing willingness of consumers to pay. A firm with a patent acts as a natural monopoly and as such would charge price p^M, given the endowments granted by patents and absence of price discrimination, the firm would sell quantity q^M, and receive a profit of p.

Consumers enjoy a surplus of *S*. Both producers and consumers benefit immediately from the patented product. When the patent expires, non-originator competitive production will eliminate profit and increase consumer surplus to p + *L*. Non-originator firms will be driven to invest in R&D due to the prospect of earning the profit flow p. If profit exceeds anticipated R&D costs of innovating new products, firms will pursue this opportunity to invest in R&D (Clancy and Moschini, p. 5, 2013).

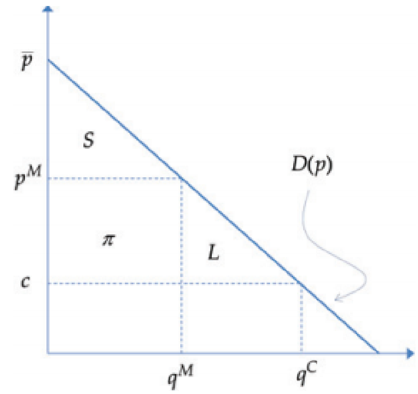

Figure 2 Patents and Monopoly Pricing. Demand and surplus model for patents in a market and its effects on consumer and firm surplus from Clancy and Moschini (2013).

Figure 2 illustrates the disadvantage of the patent grant. After the development of the new product, q^M implies that there are consumers willing to pay for the product beyond the marginal production cost. *L* represents the deadweight welfare loss based off the fact that the provision of the product is below the efficient level q^C. From an *ex ante* perspective, patents provide the necessary incentive that stirs innovations that would otherwise not happen, undersupplying innovations in the market without patents. The incentive to innovate provided by patents should encourage efficient market allocation of resources. *Ex post*, the monopolistic market established by patents implies an inefficient production of the product. For the innovators that follow the originator, the patent may not provide enough incentive because only a small percentage of the realized benefits can be earned. For example, innovation costs could exceed projected profits anticipated by a patentee monopolist, but it is lower than the total surplus, consumer surplus and producer surplus combined (Clancy and Moschini, p.210, 2013).

Sokolov-Mladenović, Cvetanović, and Mladenović (2016) find that an increase in the share of R&D expenditure in GDP, the independent variable, by 1 percent will have an impact on the growth of real GDP, the dependent variable, by 2.27 percent. This model considers the financial crises and the negative fertility rate in the EU28 on economic growth (Sokolov-Mladenović, Cvetanović, and Mladenović, p. 13, 2016). My model will differ in terms of specification, it will a non-linear model as opposed to a linear model.

IV. Methodology

The population regression model is as follows:

$$lnRDexp_{it} = \alpha_i + \beta_0 + \beta_1 lnPatentApp_{it} + \beta_2 lnSmall_{it} + \beta_3 lnDow_{it} + \beta_4 SubsGovExp_{it} + \varepsilon_{it}$$

The $lnPatentApp_{it}$ and $lnSmall_{it}$ independent variables will be interchanged with $lnPatentAppsGranted_{it}$ and $lnMedium_{it}, lnLarge_{it}$ respectively. This means we will have six regressions in total.

I have constructed the model as a double-log functional form. This is done because we can reduce the absolute size of the number associated with same actual meaning. Later this will be important in setting my expectations for the variables. This makes it easier to work out impacts in percentage terms. For example, R&D expenditure as a percentage of GDP may move up or down in percentage points, but the number of patents granted is measured in the hundreds of thousands, making it practically impossible to determine the impact of patents on R&D expenditure without a logarithmic function. All independent variables but government subsidies will be log functions.

<u>Dependent Variable: Research and Development expenditure as a percentage of GDP ($lnRDexp_{it}$)</u>

The source for the R&D expenditure dependent variable data comes from the Organization for Economic Co-operation and Development (OECD). The organization defined

R&D as a percentage of total expenditure on R&D carried out by domestic companies, research institutes, universities, and government laboratories in a country, encompassing a wide range of R&D outlets. However, the OECD excludes domestic spending for R&D expenditures on outside the domestic economy.

Although R&D expenditure is a quantitative figure and easily implementable for the purposes of my paper, it is worthwhile to note that not all technical developments are fully measurable from R&D. According the OSLO manual, the OECD guidelines for collecting an interpretation innovation data, R&D has two main limitations. First R&D is an input; it does not measure the output of technical change. Second R&D does not encompass the combined efforts of firms and governments in technical change. Other non-R&D expenditure inputs leads to the prevalence of non-R&D input measurements. Examples include development of human skills, through internal training and "learning by doing". (OECD, pg. 36, 1990). The dependent variable $RDexp_i$ accounts for the research and development expenditure as a percentage of GDP in the US and EU.

Number of patent applications ($lnPatentApp_{it}$)

Data regarding the number of patent applications is sourced from the World Bank. The number of patent application is assumed to be applications made by residents of the domestic economy. I chose to use a broad, macro measurement of patents since the scope of this paper covers the entire economies of two countries. There are more specific measurements of patents such as the "quality of patented invention" which can be measured by the scope of patents (Squicciarini, Denrnis and Criscuolo p. 10, 2013). While this adds more depth to the measurement of patents than a simple count of the number of applications for patents, it requires a very technical framework that is beyond my current ability. For the intent of this paper, I am not focusing on the dynamic effects that patents have on related and unrelated industries as that would go beyond my scope of interest. This variable is meant to generalize the relationship between R&D and patents, allowing room for depth in future papers. The main drawback of patents as innovation indicators are that many innovations are not patented, multiple patents cover some, some may not be worth any value while others have very high value (OECD, pg. 22, 1990)

Although I focus on the relationship between patents and R&D expenditure, I will include other independent variables to determine if they affect the relationship between the patent variables and R&D expenditure dependent variable.

Number of patent applications granted $lnPatentAppsGrant_{it}$)

Like the reasoning behind my first independent variable. This variable considers patents that have been approved by the respective patent office and are circulating the patent litigation system. This variable will be separately regressed by replacing the $lnPatentApp_{it}$ variable. The independent variable $lnPatentAppsGranted_{it}$ accounts for the number of patents granted at the US or EU's respective patent offices.

Firm size ($lnSmall_{it}$, $lnMedium_{it}$, $lnLarge_{it}$)

Schumpeter (1942) argues that the degree of innovation is positively correlated with protection and market power. A large firm needs costly short-run legal protection which would provide adequate short-run market power to incentivize R&D expenditure. Without protection, Schumpeter believed that large firms would not be as likely to invest in R&D and there would be no technological advancement. In economic terms, Schumpeter stated that only large firms have the capabilities to induce technological change while small firms were incapable of meaningful R&D expenditure. According to Schumpeter, small firms are incapable efficiently allocate resources for R&D in such a competitive environment.

Although Schumpeter makes a rational argument, there is a lack of empirical evidence supporting Schumpeter's hypothesis. In a mature capitalist economy, relatively large firms create large shares of technological advancement to society. While large firms' contributions are important, evidence from the past two decades of technological growth suggest that smaller firms play a significant role as well. The 1990s boom of technology reveal that small firm sizes may not be an obstacle to obtaining a share of the market value of innovation. Before the 2000s, public R&D expenditure was larger than private R&D in the 2000s, business had the largest share of R&D expenditure. Meanwhile, R&D expenditure in business were increasing in small companies. That is not to say large businesses haven't conducted R&D in the past, only that small companies are intensifying their share of R&D in technology market place (Liu, 2011, p. 36).

For this paper's purpose, firm size will encompass both small and large firms unlike other papers that do not include both simultaneously, which this paper intends to collect data on more than one class of firm size. The data collection in this paper should hopefully bear some findings to the lack of empirical evidence relating firm size and R&D expenditure despite that Schumpeter's theory is widely supported by various economists. I classify the distribution of firms in each economy based on the number of employees, ranging from small, medium, and large.

Due to preliminary findings of imperfect multicollinearity (Table 6) between the firm size variables when they're all included in the population regression, the firms size variables will be put into individual separate regression, in addition to the individual patent regressions. This means there will be six separate regressions.

<u>Government Subsidies as percentage of total government expenditure ($SubsGovExp_{it}$)</u>

Because technical knowledge can be considered a good, it can also suffer from market failure which can provide a rationale for government intervention to correct such market failures. Becker (2013) notes that R&D exhibits a classical public goods problem as it is both not completely excludable and it is a non-rival good. If the rate of private return of the R&D investment is below the social norm, which is likely if firms are unable to fully capture the returns from their R&D investment, then private returns may be lower than what is socially optimal. If firms are limited to their degree of commitment of financial resources to R&D, especially by smaller and younger firms, then R&D expenditure may again be lower than optimal. The typical financial solution would be to subsidize the economic activity required to spur positive externalities from R&D investments. Usually there are two policy tools available to governments which are R&D tax credits and direct subsidies of private R&D investments. The first approach is a free-market oriented approach, leaving the decision making and timing of investments up to the market. The second approach of government support of private R&D is possible through government-funded research in universities and public research centers (Becker, 2013, p. 22).

This variable may be troublesome due to implication of the 'relabeling' problem. Companies always aim to be cost-efficient, meaning R&D expenditures may be overestimated on monthly financial statements as a response to increase tax credit. Firms then have an incentive to maximize R&D as a percentage of total costs to qualify for tax credit. This would imply that tax credits have a positive correlation with R&D expenditure.

González (2008) finds that government support for R&D is more effective in small firms and firms which operate in low-technology sectors. It was found that the impact of subsidies on private effort becomes positive and significant. On average, subsidized firms were found to perform a private R&D effort 0.35 percentage points higher than non-subsidized firms (González, 2008, pg. 15). I account for government subsidization as a percentage of government expenditure with the variable $SubsGovExp_{it}$.

<u>Historical financial performance ($lnDow_{it}$)</u>

Because innovation, a factor that Schumpeter stresses heavily as an important factor of economic development, requires a potential plethora of research and development investment, it is only natural that one must consider that the implementation and finance of undertaking such costly investments. The financial arrangements matter in R&D spending due to the expected risks and returns of an R&D investment in each financial circumstance. Boot and Thakor (1997) suggest that high technology firms give more weight to stock market price and reaction feedback because of R&D spending. Booth, Junttila, Kallunki, Rahiala and Sahlström (2006) investigated the impact of R&D activities on market value of stocks in 20 countries. The find support for that nation that the stock markets consider firms' R&D expenditure as value-increasing activity rather than simple cost. In particular, their findings show that as equity financing intensifies, represented by the stock market, relative to bank loan financing, the stronger the R&D expenditure link (Booth, Junttila, Kallunki, Rahiala and Sahlström, p.14, 2006). For my paper's purposes, we will use the performance of the Dow Jones Industrial Average as a general indicator of equity levels of financing. The Dow Jones Industrial average accurately reflects global economic changes, meaning it will reflect the ongoing economic events in both the United States and European Union. I account for stock market performance using the variable $lnDow_{it}$.

Dataset and Sources

Patent application data was acquired from the United States Patent and Trademark Office through the statistical database Data-Planet, patents from the European Union was acquired from Eurostat, the primary database for statistics regarding the EU. Research and development expenditure as a percentage of GDP was gathered from the OECD database. Subsidies as a percentage of government expenditure was collected from the World Bank. Firm size distribution data was gathered from the U.S. Bureau of Labor Statistics and Eurostat. Acquired firm size distribution data on the European Union was more difficult than expected, databases were not as well organized and did not have complete datasets compared to the BLS's database. Dow Jones Industrial data was easily accessible from Google Finance. The US has noticeable differences to the EU in almost all regards to the dependent and independent variables. R&D expenditure is consistently above that of the EU, although both countries' R&D expenditure are steadily rising. The number of patent applications is significantly higher in the U.S. compared to the EU, the same can be said for the number of patent application granted.

V. Final Econometric Model

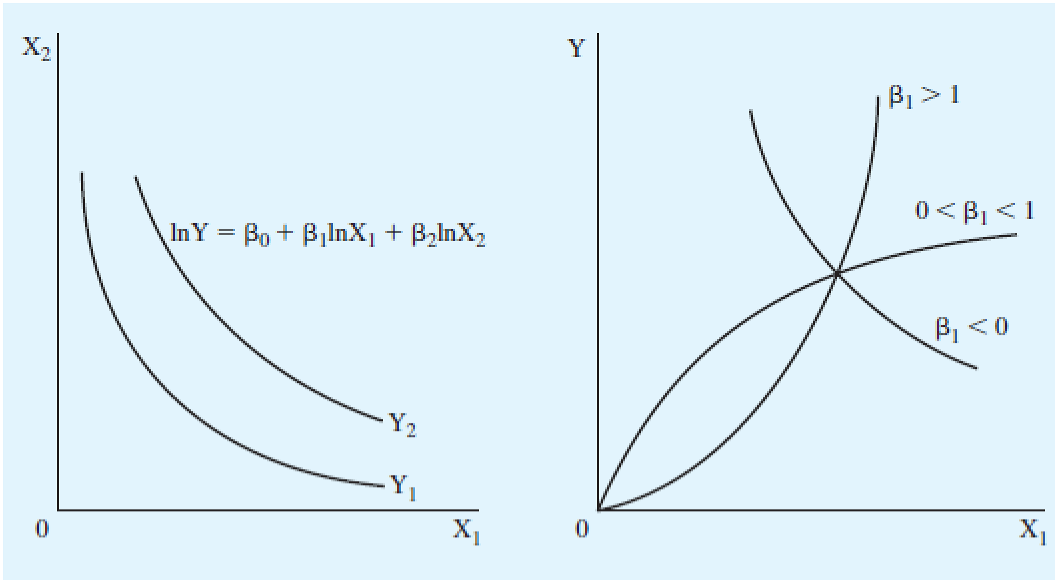

Figure 3 Double-log functions. The shapes that the double-log functional form can take. The left shows an isoquant while the right shows various shapes if X_2 is held constant or is not included in the equation (Studenmund, p. 195, 2016).

Initially the population regression model was going to be considered as a linear model due to an initial negative expectation between patents and R&D expenditure. The relationship, however, may be tied to the constant elasticities over slopes since patents are exponentially increasing while R&D expenditure oscillates (Boldrin and Levine, p.1, 2012). While it is possible for patents to have a positive effect on R&D expenditure, it may be that this positive effect is increasing at a decreasing rate. A double-log model can capture this plateau effect unlike a linear model which has constant slopes.

Since we are using a double-log regression model, the nature of the expectations will depend on whether the independent variable's correlation is bigger than one, between one and zero, or less than zero.

$\ln PatentApp_{it}$ and $lnPatentAppsGrant_{it}$ are expected to be between zero and one with R&D expenditure as the increasing number of patents in the market generates deadweight loss and inefficiency (Clancy and Moschini, 2013). In addition, referring to Figure 1, potentially higher innovation costs may stunt R&D investments. $lnSmall_{it}$ and $lnMedium_{it}$ are expected to be negative based on the Schumpeterian belief that relatively small firms are more likely to be inefficient at managing R&D expenditures while $lnLarge_{it}$ is expected to be larger than one based on the opposite expectation that large firms contribute significantly to R&D expenditure (Liu, 2011, p. 36). $lnDow_{it}$ is expected to positively influence R&D expenditure, given that sturdy financial performance across multiple industries is likely to positively correlate with R&D expenditure a value above one is expected. $SubsGovExp_{it}$ is expected to be above one since R&D subsidization helps stimulate additional R&D expenditure (González, 2008).

A panel data will be used to accommodate the cases of the U.S. and EU over two time periods. Panel data models will allow for more degrees of freedom and more variability in sampling than a cross-section. The null hypothesis states that there is no statistically significant relationship between patents and research and development expenditure while the alternate hypothesis rejects the null hypothesis:

$$H_0: p > .05$$

$$H_A: p < .05$$

Picking the fixed effect or the random effect model

Based on the population regression model we select between the fixed effect model and random effect model. Based on the p-value:

$$H_0: p > .05 \rightarrow pick\ FE$$

$$H_A: p < .05 \rightarrow pick\ RE$$

For $lnPatentApp_{it}/lnSmall_{it}$ and $lnPatentAppsGranted_{it}/lnSmall_{it}$ we reject the null hypothesis and pick the fixed effects model. For $lnPatentApp_{it}/lnMedium_{it}$, $lnPatentApp_{it}/lnLarge_{it}$, $lnPatentAppsGranted_{it}/lnMedium_{it}$ al$nPatentAppsGranted_{it}/lnLarge_{it}$ we fail to reject the null hypothesis so the random effects model is selected. By selecting the random effects model, will have more degrees of freedom than a fixed effects model, since are only estimating the parameters that describe the distribution of the intercepts rather than estimating intercepts for every cross-sectional unit. We end up with *NT-1* degrees of freedom for the random effects model and *NT – N– 1* for the fixed effects model. However, the main disadvantage is that the impact of omitted variables is assumed to be, in this case our firm size variables because of multicollinearity, is uncorrelated with the independent variables (Table 13). We also have a transformed model assuming it applies to all six regression models:

$$RDexp_{it} = \beta_0 + \beta_1 lnPatentApp_{it} + \beta_2 lnSmall_{it} + \beta_3 lnDow_{it} + \beta_4 SubsGovExp_{it} + (\varepsilon_{it} + \alpha_i)$$

Multicollinearity

The classical assumption for multicollinearity is that we assume no perfect or imperfect multicollinearity. There is no assumed relationship among the independent variables.

Using STATA's *vif* function, we search for a VIF value above five for imperfect multicollinearity. Focusing on the sample regressions' patent and firm size variables $lnPatentApp_{it}/lnSmall_{it}$, $lnPatentAppsGranted_{it}/\ lnSmall_{it}$, and $lnPatentAppsGranted_{it}/lnMedium_{it}$ had values under five. However, $lnPatentApp_{it}/lnMedium_{it}$ and $lnPatentAppsGranted_{it}/lnLarge_{it}$ had values over five, indicating imperfect multicollinearity. $SubsGovExp_{it}$ and $lnDow_{it}$ under all regressions had VIF values under five. When the patent variables $lnPatentAppsGranted_{it}$ and $lnPatentApp_{it}$were combined as one regression, regardless of which firm size variable was present individually or all together, there was extremely high multicollinearity. Likewise, when all firm size variables were included, regardless of which patent variable was present individually or altogether, there was extremely high multicollinearity (Table 3)

Heteroscedasticity

The classical assumption for heteroscedasticity is that we assume the ε_{it} variable is homoscedastic or $V(\varepsilon_{it}) = \sigma^2$. This states that the observation of the error term drawn from a distribution has a constant variance. Since panel data is simply a repeated cross-sectional model, heteroskedasticity is more likely to take place than in a time-series.

Using STATA's *hettest* function, we look for a p-value that is .05 or smaller to reject the null hypothesis and to confirm there is significant evidence of heteroscedasticity. All six regressions have p-values higher than .05. Therefore, we fail to reject the null-hypothesis and we have homoscedasticity in the regression. The reasoning could be due to the oscillating nature of R&D expenditure as mentioned by Boldrin and Levine (2012).

VI. Discussion of results

Patent variables

In all firm sizes, $lnPatentApps_{it}$ and $lnPatentAppsGranted_{it}$ was between one and zero meeting my expectations. In all cases the p-value was statistically significant at one percent. The patent variables, although all values were between one and zero, were increasing in magnitude as the firm size variable went from $lnSmall_{it}$, $lnMedium_{it}$ and $lnLarge_{it}$. This implies that patents could be correlated to firm size, possibly increasing in correlation as firm size increases. The correlation for $lnPatentAppsGranted_{it}$ and firm size, although it followed the same pattern as $lnPatentApps_{it}$, was not of the same magnitude. It seems that $lnPatentApps_{it}$, which involves the number of potential patents or patent applications, has a stronger effect on R&D expenditure. This could be likely due to the relationship between *ex ante* and *ex post* rent expectations that firms have when entering the market. An *ex ante* perspective could be correlated to the number of patent applications. In a perfect market, all information is freely available, which may true for currently existing patents. However, information regarding patent applications is not as widely available as the actual patent themselves. Firms would likely proceed with their R&D investment whether a rival has a similar patent in the process of application. Had a previous similar patent existed prior, R&D investment is likely to be decreased in magnitude due to the firm knowing about the potentially lost rents. $lnPatentAppsGranted_{it}$ can be seen from an *ex post* perspective where established patents potentially reduce the incentive to invest in R&D because now, after the fact, only a small percentage of the original profits can be earned (Clancy and Moschini, p.210, 2013). This partly answers my research questions. Since all patent coefficients have a value between one and zero we can assume patents are having an increasing effect on R&D expenditure at a decreasing rate implying a plateau effect on R&D expenditure. Although it is tempting to imply from this result that such a value implies that the costs of patents are outgrowing the output of R&D expenditure, I would require more in-depth patent variables that measure the length and quality of patents rather than just the number of patent applications and actual patents circulating the market. Patents do have a correlation, a statistically significant one (Table 1 and Table 2), however the magnitude of R&D expenditure depends on whether the patent application is still an application and not an actual patent. While Clancy and Moschini have identified potential market inefficiencies caused by patents (Figure 2), this paper places their economic theory in the context of decreasing total factor productivity using R&D expenditure as a quantitative measure. In terms of policy, on the macro side, do we limit information regarding patent applications to spur innovation, or on the micro side, do we allow for the free flow of information to allocate capital in the most efficient manner possible.

Firm size variable

It was expected that the size of a small firm would severely limit its ability to make significant contributions to its R&D investments. Although small firms had an unexpected coefficient between one and zero, implying a positive correlation with R&D expenditure at a decreasing rate. It is hard to say why this might be the case as Schumpeter (1942) only generalizes the fact that small firms cannot make significant contributions to R&D investments. However, this problem does open the need to include alternate innovation measurement indicators other than purely quantitative R&D expenditure. Qualitative measurements suggested by Sveikauskas (1986) such as managerial and organizational quality, integration of industrial relations system could help answer this unexpected coefficient, however it is again difficult to quantify such factors. According to the OECD (2005) OSLO manual, small and medium firms have ways that produce innovation through non-R&D outputs. Examples include ‘learning by doing’. Medium firm size fell within expectations, although more robust coefficients could be achieved by implementing the qualitative factors in regressions. Perhaps the most unexpected firm size coefficient was the large firm size variable as I was expecting a coefficient greater than one but received a negative value under both patent variables. Previously, I had trouble collecting data on the distribution of firm sizes from the European Union because it only included data from 2005 to 2014 whereas the U. S’s BLS provided data on the distribution of large firms from a much wider time span. The negative coefficient in a double-log function would imply a negative correlation at a decreasing rate. Under both patent variables, the large firm size variable was statistically significant at the one percent level. However, under the patent application variable, the large firm coefficient was significantly more negative than under the patent applications granted variable. The unexpected sign in the large firm variable could be partially explained by the unexpected sign in the small firm variable. At the turn of the century, firms of any size, small and medium included, could cross over most barriers to entry that its historical twentieth century counterparts wouldn’t be able to do. For example, the internet became an information super highway that anyone with a connection could access which greatly lowered the barrier of information. Schumpeter’s (1942) negative view of small firms on R&D investment stems from the capabilities of small firms at that time. Now small firms can compete with larger competitors using the internet (e.g. online retailing versus brick and mortar businesses).

Subsidization

The coefficient for subsidization did not fall under expectations. Where a value greater than one was expected, under all patent variables, the coefficients were between zero and one. The order from largest to smallest coefficient, under patent applications, was seen in the medium firm size variables, then small firm size, and then largest firms size. The coefficient value implies that the effect subsidization on R&D expenditure has a positive correlation albeit at a decreasing rate. Becker (2013) notes that firms alter their statements to acquire tax credits in the form of R&D tax credits from the public sector. This may explain why subsidization was the smallest value at the large firm size end of the spectrum. Larger firms have more to gain from tax breaks if they hold back on publicizing actual R&D expenditures, whether the R&D investment has been recorded or not. The results imply that subsidization has a stronger correlation to R&D expenditure at the small firm level. The reasoning behind the significance of small firms in relation to R&D expenditure and subsidization is beyond the scope of this paper's current literature, however it highlights the issue of measuring the effects of subsidization on R&D expenditure while incorporating firm size variables. In addition, the separation of firm sizes into separate regression was done to reduce imperfect multicollinearity, however by doing so I potentially created omitted-variable bias. It is possible that the model is trying to compensate for the separated firm size variables by overestimating or underestimating the effect of one of the other variables.

The unexpected coefficient results applied to the number of patents granted variables as well, in the same order of magnitude with subsidization having the largest effect on R&D expenditure under the medium size variable, followed by the small firm size variable, and finally having a negative correlation under the large firm size variable. It seems that the effect of subsidization on R&D expenditures does not differ in terms of positives and negatives, but it follows the similar pattern from the firm size variable discussion in that subsidization has a greater impact on R&D expenditure under the number of patent applications variable compared to the number of patents granted variable. Although the literature states there is a 'relabeling' problem in firms overestimated R&D expenditures to benefit from R&D tax credits, it is difficult to find a logical explanation as to why subsidization seems to have a greater effect in magnitude than under the number of patents granted variable. However, future research on the relationship between patents and R&D expenditure under the context of R&D tax credits could bring understanding as to why tax credits may positively or negatively impact, assuming a linear relationship, R&D expenditure depending upon firm size. Policy implications could include taking firm sizes into account for 'relabeling' where applications for R&D tax credits are concerned.

Historical financial performance

The historical performance of the financial environment, measured by $lnDow_{it}$, was expected to have a coefficient greater than one. However, under all patent variables, the coefficient was between zero to one. Similarly, to the subsidization and firm size variables, the financial environment variable had a stronger effect on R&D expenditure than under the patents granted variable. Under both patent variables, historical financial performance, under the small firm variable, had the largest impact on R&D expenditure, followed by the variable under medium firm size, and lastly the variable under large firm size which had the smallest impact on R&D expenditure. Since all values were between one and zero in all cases, it implies that past performance of stock markets had a positive effect on R&D expenditure albeit at a decreasing rate. It seems to be a recurring theme that for the variables that were expecting to have coefficients greater than one, had coefficients between one and zero. This means that there is a positive relationship between these variables and R&D expenditure, however eventually they reach an inflection point. Booth, Junttila, Kallunki, Rahiala and Sahlström (2006) only assumes a linear relationship between R&D expenditure and growth of equity, whereas my paper is specifying a non-linear double-log form. It may be more beneficial to specify historical financial performance as how well each year compared to the previous year rather than just the raw value indicator.

VII. Conclusions:

Initially, the research question began with the curiosity as to what might have been causing total factor productivity in the U.S. to decline over the past decade. I used R&D expenditure as a percentage of GDP as a quantitative measurement of innovation. The value of the coefficient of the patent variables indicated a diminishing returns effect. Based on the coefficients from Table 1 and Table 2, patents are generating diminishing marginal increases to R&D expenditure despite exponentially increasing in number. Regarding policies, although patents are exponentially increasing in number with only gaining diminishing marginal returns, it would be hasty to say that patents are detrimental to R&D expenditure as they form a crucial part of providing financial incentives for would-be innovators. On the other hand, we could be wasting potential total factor productivity gains by continuing the exponential patent trend. An optimal patent policy would be a reform that involves preserving the idea of a patent while lessening the penalties of infringement. Policies can include an improvement to improving the quality of patents to avoid another Amazon “one-click purchase” patent, or re-evaluate the litigation stance towards patent trolls to prevent out of date firms from interfering with innovative firms.

This paper gives a potential framework for the application of patents at the macroeconomic level. However, the scope of this paper does not cover the microeconomic level. A natural extension of this macro-based paper would be to analyze effect of industry-specific patents on overall industry R&D expenditure, while also taking patent length, quality, and alternate innovation measurement outlined by the OECD's OSLO manual. Clark (2016) noted that 80 percent of U.S. R&D expenditure is heavily concentrated amongst a couple of industries that only make for 20 percent of total U.S factor productivity growth. U.S. R&D expenditure is heavily concentrated around manufacturing which contributes a small portion to U.S. total factor productivity, while the service sector has a small share R&D expenditure as a percentage of GDP but makes up an overwhelming majority of U.S. total factor productivity. By looking at the effect that patents could have on the industry level, I could acquire a more precise relationship between patents and R&D expenditure.

List of tables

Table 1: Sample estimates with the number of patent application variable

VARIABLES	(1) lnPatentApps/lnSmall	(2) lnPatentApps/lnMedium	(3) lnPatentApps/lnLarge
lnPatentApp	0.170***	0.384***	0.653***
	(0.0544)	(0.0762)	(0.0970)
lnSmall	-0.0S17		
	(0.0912)		
SubsGovExp	0.012	0.018	0.002
	(0.0231)	(0.0193)	(0.0107)
lnDow	0.578***	0.487***	0.252***
	(0.0919)	(0.0827)	(0.0771)
lnMedium		-0.708***	
		(0.215)	
lnLarge			-0.439***
			(0.0727)
Constant	18.52***	25.08***	21.07***
	(1.620)	(2.039)	(0.812)
R^2	0.677	0.752	0.900
Observations	40	39	31

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2: Sample estimates the number of patent application granted variable

VARIABLES	(1) lnPatentAppsGranted/lnSmall	(2) lnPatentAppsGranted/lnMedium
lnPatentAppsGranted	0.187***	0.350***
	(0.0579)	(0.0758)
lnSmall	0.00122	
	(0.0848)	
SubsGovExp	0.00501	0.00895
	(0.0230)	(0.0198)
lnDow	0.626***	0.620***
	(0.0924)	(0.0830)
lnMedium		-0.467**
		(0.185)
Constant	18.20***	22.08***
	(1.584)	(1.731)
R^2	0.682	0.733
Observations	40	39

VARIABLES	(3) lnPatentAppsGranted/lnLarge
lnPatentAppsGranted	0.490***
	(0.179)
lnLarge	-0.275**
	(0.117)
SubsGovExp	-0.0191
	(0.0161)
lnDow	0.476***
	(0.0967)
Constant	20.87***
	(1.190)
R^2	0.789
Observations	31

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3: Robustness check for multicollinearity

	VIF	
Model	(1)	(2)
Variable	$lnPatentApp_{it}/lnSmall_{it}$	$lnPatentApp_{it}/lnMedium_{it}$
$lnPatentApp_{it}$	2.58	6.42
$lnPatentAppsGranted_{it}$		
$lnSmall_{it}$	2.62	
$lnMedium_{it}$		6.61
$lnLarge_{it}$		
$SubsGovExp_{it}$	1.07	1.27
$lnDow_{it}$	1.06	1.20

	VIF	
Model	(3)	(4)
Variable	$lnPatentApp_{it}$ $/lnLarge_{it}$	$lnPatentAppsGranted_{it}/lnSmall_{it}$
$lnPatentApp_{it}$	26.70	
$lnPatentAppsGranted_{it}$		2.28
$lnSmall_{it}$		2.30
$lnMedium_{it}$		
$lnLarge_{it}$	29.38	
$SubsGovExp_{it}$	1.07	1.08
$lnDow_{it}$	1.06	1.08

	VIF	
Model	(5)	(6)
Variable	$lnPatentAppsGranted_{it}/lnMedium_{it}$	$lnPatentAppsGranted_{it}/lnLarge_{it}$
$lnPatentApp_{it}$		
$lnPatentAppsGranted_{it}$	4.37	33.07
$lnSmall_{it}$		
$lnMedium_{it}$	4.58	
$lnLarge_{it}$		35.88
$SubsGovExp_{it}$	1.23	1.09
$lnDow_{it}$	1.13	2.13

	VIF	
Model	(7)	(8)
Variable	$lnPatentApp_{it}/lnSmall_{it}/lnMedium_{it}/lnLarge_{it}$	$lnPatentAppsGranted_{it}/lnSmall_{it}/lnMedium_{it}/lnLarge_{it}$
$lnPatentApp_{it}$	37.69	
$lnPatentAppsGranted_{it}$		48.69
$lnSmall_{it}$	113.22	95.57
$lnMedium_{it}$	48.40	53.71
$lnLarge_{it}$	85.99	133.80
$SubsGovExp_{it}$	1.03	1.16
$lnDow_{it}$	3.77	3.30

	VIF
Model	(9)
Variable	$lnPatentApp_{iti}$/ $lnPatentAppsGranted_{it}$/$lnSmall_{it}$/ $lnMedium_{it}$/$lnLarge_{it}$
$lnPatentApp_{it}$	
$lnPatentAppsGranted_{it}$	109.72
$lnSmall_{it}$	114.81
$lnMedium_{it}$	53.97
$lnLarge_{it}$	139.78
$SubsGovExp_{it}$	1.52
$lnDow_{it}$	3.89

Table 13: Hausman test

Variable	Chi-squared	P-value
$lnPatentApp_{it}$/$lnSmall_{it}$	10.75	0.029
$lnPatentApp_{it}$/$lnMedium_{it}$	4.97	0.290
$lnPatentApp_{it}$/$lnLarge_{it}$	3.19	0.367
$lnPatentAppsGranted_{it}$/$lnSmall_{it}$	12.58	0.001
$lnPatentAppsGranted_{it}$/$lnMedium_{it}$	0.92	0.921
$lnPatentAppsGranted_{it}$/$lnLarge_{it}$	0.45	0.977

Table 14: Heteroscedasticity test

Variable	Chi-squared	P-value
$lnPatentApp_{it}/lnSmall_{it}$	0.32	0.057
$lnPatentApp_{it}/lnMedium_{it}$	1.04	0.306
$lnPatentApp_{it}/lnLarge_{it}$	0.89	0.345
$lnPatentAppsGranted_{it}/lnSmall_{it}$	0.11	0.742
$lnPatentAppsGranted_{it}/lnMedium_{it}$	0.32	0.572
$lnPatentAppsGranted_{it}/lnLarge_{it}$	0.36	0.548

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