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Can Policy Spur Technological Growth?

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Can Policy Spur Technological Growth?

By

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Honors in the Department of Economics

UNION COLLEGE
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Abstract:

The long-term slowdown in productivity growth for OECD countries, despite increased resources allocated to R&D, has once again raised the issue of limits of technological change. I explore the relationship between labor productivity growth and R&D intensity, using macro-level panel data from OECD countries. My empirical analysis essentially tests the semi-endogenous growth theory against the fully-endogenous Schumpeterian growth theory. The semi-endogenous framework assumes diminishing returns to R&D and requires positive population growth to generate long-run growth. The fully-endogenous framework assumes growing product variety and requires a constant share of R&D inputs in overall inputs in order to generate positive long-run growth. My empirical findings are more supportive of the semi-endogenous growth models. The results thus imply that policy changes that increase the share of resources allocated to R&D may have little impact on productivity growth.

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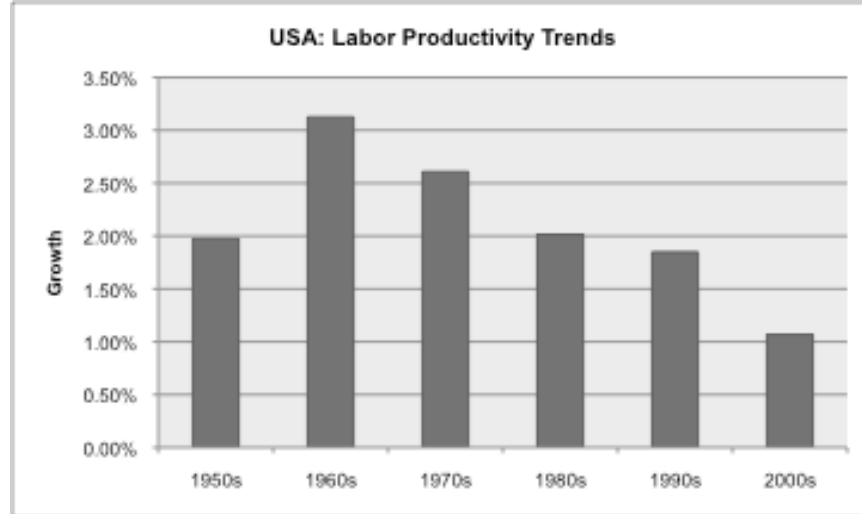
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1.0 Introduction:

In a recent paper, entitled “Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds” Gordon (2012) reignites the debate over the future prospects of innovation and technological growth. Those optimistic of future technological advances cite human ingenuity and can point to several instances in history where prominent figures have stated that innovation is over, only to be proven wrong time and again. Those individuals such as Gordon who have a more pessimistic vision of future innovation look to the standard of living and see the most profound impacts have come in the past. Innovations such as running water, heating, and electricity in the household were “one-time” changes in the way that humans live. Due to these innovations having already been implemented in developed societies, it’s difficult to imagine any innovation having as great an impact on the daily life as those from the past already have. Using Schumpeterian (R&D Induced) Growth Theory I test the state of technological opportunity and the diminishing nature to R&D. The conclusions I find give strength to the claims that there is a diminishing nature to the R&D effort.

The motivation behind this paper goes beyond the debate over faltering innovation but comes about from observed productivity growth declines in the United States paired with an increased R&D intensity.

Figure 1:



Note: Labor Productivity Growth is calculated as per capita GDP (\$1990) / total hours worked per capita giving output per capita. Growth calculated on a year over year basis. Observations in this figure are taken as average growth over 10 year periods.

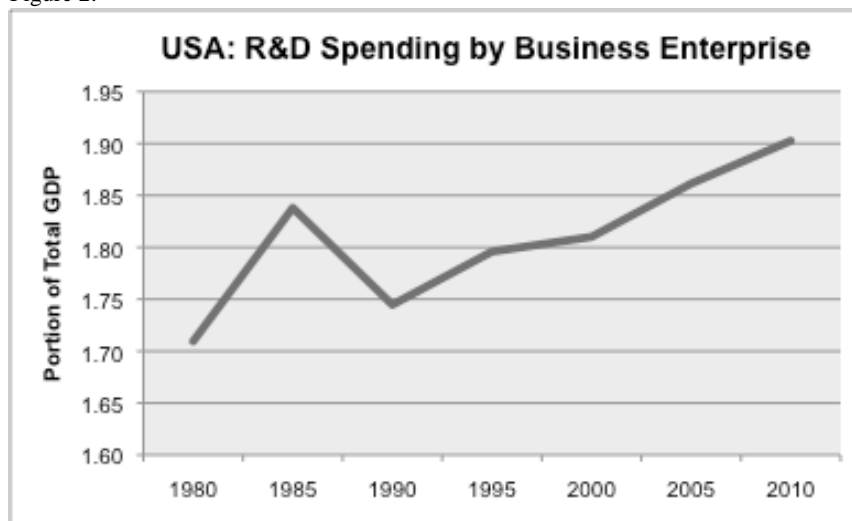
Figure 1 presents the decade trends for labor productivity growth in the United States from 1950 to 2010. The United States hit peak productivity growth in the 1960s with an average growth of 3.12% throughout the decade and by the 2000s it had fallen to 1.07%. The measurement for the 2000s is inclusive of the 2007 recession and slow recovery as a result the growth of productivity for the decade is biased. However, even if productivity growth were similar to that of the 1990s, growth would still be over a whole percentage point lower than those of the 1960s.

The downward trend in labor productivity is striking because of the link that exists between technological growth and labor productivity growth. Technological growth spurs labor productivity growth. To better understand this relationship a thought experiment is useful. If it takes one hundred lumberjacks with axes, an hour to cut down one hundred trees, the per capita output would be one tree per hour. Now imagine there are one hundred lumberjacks with chainsaws who can cut down one hundred trees in

one minute, the per capita output would be one hundred trees per minute. The avenue to productivity growth in this example is the chainsaw, technological change. This is a very simple example and when applied to the aggregate the process becomes more complicated, but the link still exists. For example, Madsen (2010) finds that capital plays a role in productivity growth. A worker becomes more productive if they have more capital available to them.

These labor productivity trends are not only provocative on their own, but the trend in R&D intensity illustrates an increased effort without seeing that impact in productivity growth. Figure 2 shows the trends in R&D spending in the United States from 1981-2012.

Figure 2:



Note: Business Enterprise R&D Spending (BERD) is calculated as a portion of total GDP. 5 year averages are taken for each observation point.

As can be observed, besides a steep drop in spending in the late 1980s, there has been an increasing effort with regards to R&D. Although growth of 0.3% between 1980 and 2010 may seem like a trivial amount, intuition tells us that a growing effort in

R&D should have a positive impact on the rate of technological growth, or productivity growth. The data shows that productivity growth has been in decline even with the increased R&D effort. These provoking trends lead me to question technological opportunity in the future and whether policy could reverse the labor productivity trends and boost technological growth.

Literature has long dealt with R&D induced technological growth, and papers such as Romer (1990) were among the first to construct endogenous growth models. These endogenous models assume that the labor supply and R&D difficulty are constant. In the steady state, the endogenous model predicts a constant rate of technological growth. In this model, any policy initiative that can increase the labor supply, through scale effects, exponentially increases technological growth.

Following the endogenous model a new theory emerged to explain similar trends I observe in R&D inputs and technological growth indicators. The first wave of literature to come out was the semi-endogenous theory in papers such as Jones (1995b), Kortum (1997) and Segerstrom (1998). This theory explains that declining R&D productivity is a result of diminishing technological opportunity and diminishing returns to R&D. In this theory the avenue to achieve a balanced growth path is to growth the labor supply, and by assumption policy will have no impact on the rate of technological growth.

After the semi-endogenous strand of literature, a fully endogenous theory began to appear in papers such as Peretto (1998), Young (1998), and Howitt (1999). These papers argue that the trends in the data can be explained through product proliferation. As an economy grows the variety of products also grows resulting in the

resources to R&D being equally distributed over an ever-increasing field of products. In this strand of literature the way to attain a balanced growth path is to maintain the fraction of total inputs devoted to R&D, and by assumption policy can impact the technological growth rate.

The semi-endogenous theory cites declining technological opportunity as a reason for the declines in productivity, and it is worthwhile to understand what technological opportunity is. Olsson (2005) develops an excellent approach to technological opportunity and I use his work in my explanation. There are three types of products that can shift and impact technological opportunity: incremental innovations, radical innovations, and discoveries. Incremental innovations are small changes in existing technologies that refine knowledge but are not revolutionary. Radical innovations are radically new ideas that are attained after deliberate attempts to combine previously unrelated ideas. Radical innovations shift the technological paradigm. A discovery is a completely new piece of knowledge that is usually discovered accidentally. Initially, discoveries are not usually marketable products and sit in an island outside of the technological paradigm until the knowledge is later used in the creation of a radical innovation, opening up technological opportunity.

To clarify these ideas further imagine the radical innovation of the automobile, which combined the internal combustion engine with wheels and a seat. The automobile opened up a whole new field of technological opportunity, which has since been slowly filled with incremental innovations such as adding air-conditioning and power windows to the automobile. The classic example of a discovery is Alexander Fleming's accidental discovery of penicillin, which would then become a critical

medicine for mankind. Another way to think of discoveries is to look to the Scientific Revolution where pioneering findings in physics, chemistry, and biology were made. However, it was not until much later when those findings were actually applied to usable innovations. For example, Newton's first law of motion, an object in motion will remain in motion unless acted upon by an outside force, formed the scientific basis for the innovation of the seat belt in the car. The theoretical foundations for the seat belt were thought of during the scientific revolution but it was not for hundreds of years until the seat belt was actually invented.

There is existing literature that empirically tests the Schumpeterian models and specifically the fully and semi-endogenous models. Zachariadis (2004) uses aggregate and manufacturing data from 10 OECD countries between 1971 and 1995. He tests the impact of R&D intensity on productivity growth and productivity growth on output growth. In conclusion, Zachariadis (2004) finds evidence in support of the fully endogenous model and against the semi-endogenous model. Madsen (2007) uses aggregate data from 21 OECD countries between 1965 and 1995.¹ He tests whether the fully and semi endogenous models exhibit constant returns to R&D. Madsen (2007) finds evidence against the underlying assumptions of the semi and fully endogenous models. Venturini (2012) utilizes data from 20 US manufacturing industries from 1975-2003. The evidence that Venturini (2012) finds is more supportive of the fully endogenous model.

Although my paper tests the same semi and fully endogenous models as those papers above, it differs in several ways and brings new breath to the literature. One such

¹ The time horizon that Madsen (2007) uses varies, with data for certain countries going back further.

way is that I use data observations that are taken at five-year periods. None of the three papers above use observations at five-year periods and to the best of my knowledge there is no existing literature that utilizes data in this way. Although the data I use does not extend back as much as other papers such as Madsen (2007) who goes back to 1965 and earlier, I incorporate more recent data into my analysis. Some may criticize using more recent data as it is inclusive of the recession beginning in 2007, however my five-year average data observations smooth the business cycle noise. I use aggregate data while some studies use industry level data or both. One reason for my using only aggregate data is that Zachariadis (2004) finds that there is an advantage of using aggregate data when studying the effects of R&D because of R&D spillovers that are potentially captured.

Much of the existing literature uses patent data as a proxy for innovation output such as Venturini (2012) and Madsen (2007), while I focus on productivity growth as an indicator for innovational output similar to Zachariadis (2004). Unlike Zachariadis (2004) who uses total factor productivity, I use labor productivity as my main indicator for innovational output. I do also use total factor productivity, but my motivation for this paper stems from the trends in labor productivity, and I include total factor productivity for robust purposes. Although patent data has steadily improved through tracking patent quality (forward citations, backward citations, claims), it fails to capture processes and products that go unpatented, while labor productivity captures all process and product innovations, whether or not they are patented.

I include variables capturing technological adaptation growth of items, such as the Internet, into my analysis. To the best of my knowledge there is no existing

literature that is inclusive of technological adaptation growth variables, and so my analysis being new thought to the current literature. It is on these grounds that my paper provides a unique perspective to the existing literature on Schumpeterian growth.

The first goal of this paper is to empirically assess whether the semi-endogenous or fully endogenous models can better explain the trends in the data. Semi-endogenous theory reasons that the downward productivity trends is due to diminishing returns to the R&D effort, while fully endogenous theory predicts that this trend is due to product proliferation. Evidence in favor of semi-endogeneity would imply that the average worker is becoming less productive, while evidence in support of fully endogeneity implies that workers are not becoming less productive but are being spread among a growing industrial field.

The second goal of this paper is to determine whether policy to increase the resources to R&D can impact technological growth. By assumption, these policy directives under the semi-endogenous model have little to no impact on the growth rate of technology. Under the fully endogenous model, policy directives can impact the rate of technological growth. Policy implications are important as it determines whether a government can directly impact technological growth.

In order to accomplish these goals I run baseline regressions for each of the theories, which I then build upon to test the impact of education and technology adaptation growth on productivity. The baseline regressions I run give overwhelming support to the semi-endogenous theory and as I expand the analysis to include other parameters I also find support for the fully endogenous theory. The high significance of the semi-endogenous regressions in the baseline leads me to conclude that this theory

gives a better explanation of the productivity trends than the fully endogenous theory even though I find support for the fully endogenous theory.

The rest of the paper is organized as follows. Section 2 reviews the relevant literature I use in the study with regards to Schumpeterian Growth, empirical tests of Schumpeterian Growth, and observational/policy essays. Section 3 presents the models based off foundations borrowed from Dinopoulos and Sener (2007) and Venturini (2012). Section 4 discusses the data I use in this study. Section 5 presents the econometric specifications that I test. Section 6 illustrates the descriptive statistics and regression results. Section 7 concludes. Technical details surrounding my data and country specific standard deviations appear in the appendix.

2.0 Literature Review:

The existing literature on innovation and technological change is vast and much of it goes beyond the focus of this paper. The literature that has helped to motivate and shape this study falls into three sections: the literature on Schumpeterian growth, literature that empirically tests Schumpeterian growth, and policy/observational papers.

2.1 Schumpeterian Growth Model Literature:

The literature on Schumpeterian growth must begin with Romer (1990), which was one of the first papers to develop an endogenous model with technological change at its heart. The paper lays out three premises that are the base for his argument:

technological change lies at the heart of economic growth, technological change arises in large part because of intentional actions taken by people responding to incentives, and instructions for working with raw materials are inherently different from any other economic good. In his endogenous model population and the supply of labor are constant. If there were policy initiative to devote more human capital to research it would lead to a higher rate of new innovations. Innovation increases the stock of knowledge and would therefore increase the productivity of human capital in research. The paper concludes that an economy with a larger stock of human capital would have a higher rate of growth. When this model failed to explain declining patents per researchers and declining productivity growth criticism of the endogenous model emerged.

This criticism came in the form of a semi-endogenous growth theory that was able to explain the trends that the endogenous model could not. Kortum (1997), and Segerstrom (1998) are two such papers that present semi-endogenous growth models. Kortum (1997) was written to explain why research inputs have been growing while patents per researcher have fallen and total factor productivity has not increased in line with research inputs. This generation of literature introduced R&D difficulty into the model, when it had been excluded in the previous generation. The paper finds that patents per researcher decline as innovation becomes more difficult. In conclusion the model predicts that the number of researchers must rise exponentially in order to generate a constant rate of patents.

Segerstrom (1998) presents a similar model where he explores the theoretical implications of research and development becoming more difficult. The semi-

endogenous models exhibit diminishing returns to the R&D effort because of the average worker becoming less productive as research becomes more difficult. Just as this strand of semi-endogenous literature emerged critics began to develop an endogenous model with product proliferation, the fully endogenous theory.

The fully endogenous growth model is the second Schumpeterian theory that this paper will focus on and is presented extensively in Aghion and Howitt (2009, chapter 3) among others. The fully endogenous theory has the underlying assumption that as an economy grows so do the variety of products that are available in that market. As a result, R&D resources then get split between the different products, therefore the greater variety of products in a economy the smaller share of R&D resources each gets.

The debate over which model, semi or fully endogenous can best explain growth in technology continues to the present and Dinopoulos and Sener (2007) follow the progression of Schumpeterian growth models. The paper discusses the endogenous, semi-endogenous, and fully endogenous models and lays out how the literature has impacted each theory. There is also extensive discussion on the scale-effect and how the semi and fully endogenous theories have taken out the scale-effect that exists in the endogenous model. This paper truly does a superb job in explaining the various models and directions each has taken.

2.2 Literature Concerning Empirical Tests of Schumpeterian Models:

Zachariadis (2004) makes the connection between aggregate R&D intensity and productivity/output growth. The author finds there exists a positive relationship between R&D intensity and growth rates. The paper shows that R&D impacts productivity and that productivity in turn impacts the growth rate. The connection he finds is useful in my study as it gives justification for my testing the relationship between R&D and productivity. In his tests he finds support for the fully endogenous model and evidence against the semi endogenous model.

In the short economic letter, Madsen (2007) tests whether there are diminishing returns to R&D. He tests the null hypothesis of constant returns to R&D and finds that it cannot be rejected. He concludes that the assumptions of the semi-endogenous growth theories cannot be maintained and that the product proliferation assumption of the fully endogenous theories needs to be toned down. This is a challenge to the Schumpeterian Models and almost a plea for someone to make them better.

Venturini (2012) empirically tests the generations of Schumpeterian growth models. The paper tests the different models using industry level data and patents as an indicator for innovation. He finds more evidence in support of the second generation Schumpeterian model than the semi-endogenous model.

2.3 Observational/Policy Literature:

Knowledge is an important aspect of growth models and Jones (2009) paper discusses education and the increasing educational burden that researchers have to undergo. Knowledge is not something that you are born with but you acquire through

years of schooling. The paper finds that innovators in areas of deep knowledge combat the vast sum of knowledge through longer educational periods, a narrower expertise, or teamwork. The paper explains that the burden of knowledge can explain why increasing R&D workers and expenditure is not associated with productivity growth and patenting rates. Essentially the amount of knowledge that a researcher will have to absorb is so large that it is becoming more difficult to innovate. More often than not it is the researchers who make great discoveries, and so it is important to understand the theoretical background for human capital accumulation in deep fields of study.

Labor productivity is an important indicator in tracking the rate of innovation but has some shortcomings such as the fact that capital deepening can significantly impact labor productivity. Madsen (2010) deals with capital accumulation and productivity issue. The paper goes on to find that any technological innovation breakthrough increases the expected returns and as a result lead to capital deepening. In addition, factors such as expected stock returns and tax rates will influence capital accumulation and impact productivity. The paper also shows that capital adjustments are made within a decade or two from the time of an innovation.

Dinopoulos and Syropoulos (2007) offers a different explanation to the decreases in R&D productivity. They argue that rent protection is making research and development more difficult. Rent protection has the fundamental aim of decreasing the productivity of R&D. As an economy grows it become increasingly difficult to innovate because there are more resources devoted to rent protection. Incumbent firms will expend more resources towards rent protection forcing competitors to in turn expend more resources on R&D. This paper offers an alternative view on why research and

development is becoming more difficult and adds incite to the many mechanisms that are at play with regards to R&D.

In order to get a sense of technological opportunity, Olsson (2005) discusses how technological opportunity can help explain the output declines in R&D workers as well as innovation potential. The paper outlines three types of innovations (incremental, radical and discovery) and how they impact and shift technological opportunity. The paper finds that human capital engaged in R&D increases as population grows and as the technological opportunity is exploited. The paper also finds that R&D output is dependent upon technological opportunity rather than the existing technological knowledge. The paper has some insightful findings, but the key section within the paper for my study is the discussion of the three types of innovation.

In a very interesting working paper, Gordon (2012) lays out an argument that the growth of the past 250 years was a one-time event and economic growth is converging to near zero rates. This strong growth was caused by the cluster of innovations that dramatically changing the standard of living. Innovations in the future are not going to be as impactful on growth due to factors harboring the economy that he calls the six headwinds: demographics, inequality, education, globalization, energy/environment, and debt. Gordon sees these headwinds as detrimental to economic growth as we know it. Even if innovation continues the impact on growth will be minimal because of the headwinds.

3.0 Models:

In this section I re-create the building blocks of the Schumpeterian growth model and the specifications that the semi and fully endogenous models follow. Following this I explore the returns to R&D under the semi and fully endogenous model. I re-create these models from framework given in Dinopoulos and Sener (2007) and Venturini (2012)

3.1 Schumpeterian Growth Model:

Schumpeterian growth has evolved over three generations of models. The first generation of these models such as Romer (1990) has assumptions of a constant labor force and a constant R&D difficulty. These assumptions are unrealistic and as so this paper focuses on the second and third generation, which will henceforth be referred to as semi-endogenous and fully endogenous. The semi-endogenous theory, Kortum (1997) and Segerstrom (1998), assumes that there is diminishing technological opportunity and returns to R&D. Thus to maintain a constant growth rate in equilibrium there needs to be growth in R&D inputs. The fully endogenous theory, Dinopoulos and Thompson (1998) and Howitt (1999), assumes that as an economy grows the number of products offered will widely expand, forcing the R&D inputs to be spread over a larger number of goods, implying diminishing returns unless the fraction of R&D inputs devoted to R&D is constant. Using theoretical foundations from Dinopoulos and Sener (2007) and Venturini (2012) I recreate the model's. To simplify the discussion of the models, I will begin with a simple economy. In this economy the final output production function is as follows:

$$(1) \quad Y(t) = A(t)L_Y(t)$$

where $Y(t)$ is the economy's total output, $A(t)$ is the level of technology, and $L_Y(t)$ is the labor devoted to manufacturing. The following function gives us the production function of knowledge:

$$(2) \quad g_A \equiv \frac{\dot{A}(t)}{A(t)} = \frac{L_A(t)}{X(t)}$$

where g_A represents the growth rate of technology, $L_A(t)$ is the total labor resources devoted to R&D, and $X(t)$ is the measure of R&D difficulty. As can be inferred, higher labor resources would result in a higher technology growth rate, *ceteris paribus*. In addition, if R&D difficulty is increasing as the recent trends in productivity growth implies, growth in R&D labor would be required to maintain the balance growth path. In this simply economy the labor employment function is as follows:

$$(3) \quad L(t) = L_Y(t) + L_A(t)$$

where $L(t) = L_0 e^{g_L t}$ indicates the level of the labor force at time t ; and where $g_L > 0$ and is representative of the population growth rate. In this economy the labor force is only

comprised of workers in manufacturing or R&D; it can be assumed that if a worker is not engaged in manufacturing they are engaged in R&D or vice versa. In the steady state the growth of output per capita is:

$$(4) \quad g_y \equiv \frac{\dot{y}(t)}{y(t)} = \frac{\dot{A}(t)}{A(t)} = (1-s) \frac{L(t)}{X(t)}$$

where g_y is output per capita, s is the share of labor engaged in manufacturing, and $(1-s)$ is the share of labor engaged in R&D. It can be seen that as the R&D difficulty parameter $X(t)$ grows, holding all else constant, the output per capita will fall. In addition, we can get the per capita resource equation by dividing both sides of equation (3) by the population level and substituting $L_A(t) = g_A X(t)$ we get:

$$(5) \quad s + g_A \frac{X(t)}{L(t)} = 1$$

The five equations above are the building blocks of Schumpeterian growth, and what follows in this section will be the specifications of the two models built off the assumptions and foundations discussed above.

3.2 Semi-Endogenous Specifications:

To explore the foundations for the semi-endogenous model and diminishing technological opportunity we will assume that as the knowledge, $A(t)$, increases so will the difficulty of R&D, $X(t)$:

$$(6) \quad X(t) = A(t)^{1/\varphi}$$

where $\varphi > 0$ and is a parameter capturing the diminishing technological opportunity. Because in the steady state $X(t)/L(t)$ is constant it implies that the growth of R&D difficulty must be equal to the growth rate of labor, g_L . This gives us:

$$(7) \quad g_A = \varphi g_L$$

Equation (7) shows that growth rate of technology is proportional to the growth rate of labor. This implies that the growth rate of technology under the semi-endogenous framework can be impacted through growth in labor. This is highly dependent on the technological opportunity, if $\varphi < 1$ there will exist diminishing returns to the R&D effort. Because of the assumption that policy cannot directly affect the population growth rate or φ capturing the technological opportunity, policy directives cannot impact long run technological growth. As a result this model is considered semi-endogenous or exogenous.

3.3 Fully Endogenous Specifications:

To illustrate the fully endogenous model I begin in (8) with the production of knowledge in a given industry:

$$(8) \quad g_t \equiv \frac{\dot{A}_t(t)}{A_t(t)} = l_A$$

where g_t is industry-specific rate of technological change, $A_t(t)$ is the industry-specific level of technology, and l_A is the number of R&D workers employed in a typical industry. Taking aggregate output as, $Y(t) = A_t(t)l_z n(t)$, where l_z is the number of workers in manufacturing and $n(t)$ is the number of structurally identical firms producing a variety of goods. The per capita output $y(t) = Y(t)/L(t)$ which yields:

$$(9) \quad g_y \equiv \frac{\dot{y}(t)}{y(t)} = l_A + \frac{\dot{n}(t)}{n(t)} - g_L$$

where g_L is the population growth rate. Equation (9) implies that as the number of firms producing different good grows, the output per capita falls. In order to find the long run per capita growth rate I substitute $\dot{n}(t)/n(t) = g_L$ in (9), giving:

$$(10) \quad g_y = \frac{\dot{A}_t(t)}{A_t(t)} = l_A$$

Equation (10) implies that any policy directive that changes the distribution of labor between manufacturing and R&D can affect long-run growth. Specifically, policy that increases the R&D labor will positively impact the long run growth of technology.

3.4 Returns in Semi and Fully Endogenous Classifications:

To better understand the returns to R&D we will start with a function depicting the growth in knowledge in the steady state:

$$(11) \quad \frac{\dot{A}}{A} = \lambda \left(\frac{X}{Q} \right)^\sigma A^{\phi-1}$$

where \dot{A} is the annual flow of new ideas, A is the stock of knowledge, X is R&D inputs, Q is product proliferation that is associated with population $L (Q, \alpha L_t^\beta)$, λ is research productivity and σ is a duplication parameter, which equals 0 when innovations are replications of existing products and 1 when there are no duplicates. β is the coefficient

of product proliferation, and ϕ captures returns to scale in knowledge production. In the semi endogenous classification $\phi < 1$, $\beta = 0$, and $\sigma > 0$. In the fully endogenous classification $\phi = 1$, $\beta = 1$, and $\sigma > 0$. Applying these classifications to the growth in knowledge function in (11) yields:

$$(12) \quad \frac{\dot{A}}{A} = \lambda(X)^\sigma A^{\phi-1}$$

$$(13) \quad \frac{\dot{A}}{A} = \lambda\left(\frac{X}{L}\right)^\sigma$$

In the semi endogenous equation (12) there is no product proliferation and as can be seen R&D inputs are highly dependent on the productivity of research. Because $\phi < 1$, there is a decreasing returns to scale in the production of knowledge. In the fully endogenous equation (13) the growth in technology is dependent on product proliferation. Even if the productivity of researchers is high, the growth in technology is still dependent on the growing product field. In this classification because $\phi = 1$ there are constant returns.

In conclusion, the semi-endogenous framework predicts diminishing returns because as the level of technology increases and the technological opportunity becomes less the individual worker will become less productive, and so to maintain a balanced growth path there must be an increasing number of workers engaged in R&D. The fully

endogenous theory predicts this because of a growing variety of products that R&D inputs must be evenly dispersed among, and so to maintain a balance growth path a constant fraction of inputs must be allocated to R&D.

4.0 The Data

In this section I discuss the data I gathered and the particulars of each variable that I use. The statistical analysis I perform uses panel data encompassing 25 out of 34 OECD country members and 1 non-OECD member for the period between 1980 and 2010.² A list of the countries I used in this study is available in the appendix. The data observations are taken at 5 years intervals in order to smooth the business cycle noise in the data. The construction of these observations was done in the format that the average value from 1980-1984 is recorded as the observation for 1980, 1985-1989 for 1985 and so forth. For five-year periods where data for one or more years is unavailable, the observation is taken excluding missing years. For example if data for the year 1981 is unavailable the observation 1980 is comprised of the averages from 1980, 1982, 1983, and 1984.

The productivity growth data I use as measurement of technological growth is in two forms, labor productivity growth and total factor productivity growth. Labor productivity is calculated by dividing per capita GDP by the annual hours worked per

² Note that the time period for variables TFP, Personal Computer, Cell Phone, and Internet is limited due to the lack of available data.

capita using data from the *Conference Board's Total Economy Database*.³ Labor productivity growth is then equal to the difference of labor productivity between years t and $t-1$. Total factor productivity growth data was also gathered from the *Conference Board's Total Economy Database*.⁴ The data available for total factor productivity is limited between the period 1990 and 2010.

The data I utilize for R&D Intensity comes under two sections, R&D intensity measured through labor and R&D intensity measured through expenditure. The R&D labor measurements are total R&D personnel (annual growth rate) and total researchers (annual growth rate) with the data gathered from OECD *Main Science and Technology Indicators*.⁵ The broad definition of R&D labor is total R&D personnel, which is defined as all those researchers, technicians and equivalent staff, and support staff engaged in R&D.⁶ The narrow definition of R&D labor is total researchers, which is defined as professionals engaged in the creation of new knowledge, products, processes, methods, and systems as well as the management of these projects.

Data I use for R&D intensity as expenditure is measured in four distinct ways: BERD, GERD, HERD, and GOVERD which were all gathered from OECD *Main Science and Technology Indicators*.⁷ BERD is the business enterprise expenditure on R&D as a fraction of GDP, which is comprised of all R&D expenditure by profit seeking enterprises. GERD is gross expenditure on R&D as a fraction of GDP, which is comprised of all expenditure in a given country in a given year. GOVERD is the

³ A more detailed explanation of the calculation for Labor Productivity Growth appears in the appendix.

⁴ For more detail on Total Factor Productivity see appendix.

⁵ For more discussion of the Main Science and Technology Indicators, see appendix.

⁶ Note that total R&D personnel data is unavailable for the United States.

⁷ For more explanation of the R&D expenditure data, see appendix.

government expenditure on R&D, which is comprised of all federal and state/provincial (when significant) expenditure on R&D in a given year. HERD is the higher education expenditure on R&D, which is comprised of mostly general university funds (GUF) and external funds devoted to R&D within higher education institutions. Table 1 shows the summary of variables and the abbreviations that I use throughout the paper.

Table 1: Summary of variables

Variable	Abreviation
Labor Productivity Growth	LPG
Total Factor Productivity Growth	TFP
Total R&D Personnel Growth	RDPG
Total Researchers Growth	RLG
Business Enterprise R&D Expenditure	BERD
Gross Domestic R&D Expenditure	GERD
Governmental R&D Expenditure	GOVERD
Higher Education Expenditure on R&D	HERD
Cell Phone Unit Growth	CELL
Personal Computer Unit Growth	PC
Internet Access Growth	INTERNET

The data I use to account for human capital is the average educational attainment for total population aged 15 and over. The data was gathered from the *Barro-Lee Educational Attainment Dataset*.⁸ The educational attainment is measured in years with twelve years being equivalent to a high-school education in the United States. The Barro-Lee dataset has intervals set at every five year, which allows the data to be transferred with minimal disruption.

⁸ For more details of the Barro-Lee dataset, see appendix.

For robustness purposes I use data tracking the growth of recent innovations, gathered from the *Cross-country Historical Adoption of Technology (CHAT) dataset*.⁹ The first indicator I use is cellphone, which tracks the units of cellphones in a given country with data available from 1985-2000. I then calculate the growth in cellphone units as the difference between units at t and $t-1$. I then use the indicator computer, which is comprised of the personal computer units in a given country in a given year; I then calculate the year over year growth of PC units. The final indicator I use from CHAT is Internet user, which is measured as the number of individuals with access to the Internet, with data available from 1990-2000. I then use this raw data to calculate the year over year growth of those with access to Internet.

5.0 Econometric Specifications

In this section I provide specifications for the econometric tests I run based off the framework and assumptions discussed in the model section. In my tests I use two dependent variables, labor productivity growth and total factor productivity growth to account for growth in technology. Semi-endogenous theory allows for constant growth in the steady state as long as there is a growing R&D Inputs to offset the diminishing returns, and in my study I use R&D labor growth to account for this. In fully endogenous theory a higher growth rate can be achieved through allocating a larger

⁹ For more discussion of the CHAT dataset, see appendix.

fraction of R&D inputs to offset the diminishing nature that product proliferation has and in my study I use R&D expenditure as a fraction of total GDP to account for this.

The four equations below show the basic structure of the regressions I run. Equations 1 and 2 illustrate the semi-endogenous framework while Equations 3 and 4 illustrate the fully endogenous framework.

Equation 1:

$$LPG_{i,t} = \beta_0 + \beta_1 RDLG_{i,t} + \Psi_i + \theta_t + \alpha_{i,t} + \varepsilon_{i,t}$$

Equation 2:

$$TFP_{i,t} = \beta_0 + \beta_1 RDLG_{i,t} + \Psi_i + \theta_t + \alpha_{i,t} + \varepsilon_{i,t}$$

Equation 3:

$$LPG_{i,t} = \beta_0 + \beta_1 BERD_{i,t} + \Psi_i + \theta_t + \alpha_{i,t} + \varepsilon_{i,t}$$

Equation 4:

$$TFP_{i,t} = \beta_0 + \beta_1 BERD_{i,t} + \Psi_i + \theta_t + \alpha_{i,t} + \varepsilon_{i,t}$$

Where Ψ_i captures the fixed country effects, θ_t captures the fixed year effects, and $\alpha_{i,t}$ captures the country specific linear time trends. The subscript i denotes that the

variable is country dependent and the subscript t denotes that the variable is time dependent. LPG is labor productivity growth and TFP is total factor productivity growth. RDLG is representative of R&D labor growth, which is measured, in a broad definition (total R&D personnel growth) and a narrow definition (total researchers growth). BERD is representative of expenditure on R&D (as a fraction of total GDP).

I use fixed effects to control for variations that are country or time dependent. I also use country specific linear time trends to account for time trends that exist within a country. I do this in order to account for any variations that could impact the results, such as a global recession.

The statistical tests I run, for robustness reasons, extend from the basic structure depicted in the equations above to include other parameters. For the R&D expenditure I expand the measurements from just business enterprise to include government expenditure, higher education expenditure, and gross national expenditure. However, business enterprise expenditure is the measurement I am most concerned with.

There is a test specification that I run that is inclusive of a human capital variable. In addition I also run tests that include variables accounting for the growth in recent (within the time period of this study) technological adaptations.

The indicators that I utilize for R&D labor, both the broad and narrow definition, I expect to be positively correlated to productivity growth. Theory tells us that the way to offset the diminishing R&D effort is to increase the number of workers engaged in that effort. Economies with the ability to continuously muster more individuals to battle it out in R&D races are expected to have a higher productivity rate.

The variables I use to account for R&D expenditure I expect to have a positive correlation to productivity growth. As the theory portrays, the only way to maintain positive growth in technology, or productivity, is to maintain a constant fraction of resources devoted to R&D inputs. Countries with a larger fraction of GDP devoted to R&D inputs would be expected to experience a higher rate of productivity growth.

I expect that the human capital variable I use to be positively correlated to the productivity growth as theory predicts that as the base of knowledge increase the average productivity of the individual worker will increase. This implies that a country with high educational attainment would see higher productivity than a country with a lower base of knowledge.

I expect that the variables tracking specific technological adaptation growth to be positively correlated to productivity. Innovations have the ability to increase the productivity of the individual greatly. The technologies I track as variables are cell phones, personal computers, and Internet access. Intuitively, cell phones allow for communications on the go, computers allow for ease in accomplishing repetitive and dull tasks, and the Internet connects the individual to a revolutionary paradigm of access to information. Higher growth in these variables I expect to equate to higher productivity levels.

6.0 Descriptive Statistics and Empirical Analysis

In this section I will first present the descriptive statistics of the variables I use in the empirical analysis. The section will then present the regression results from the

conditions outlined in the econometric specifications section. In this section I begin with the results from the baseline semi and fully endogenous classifications using labor productivity growth as the dependent variable followed by the results using total factor productivity growth. Then, for robustness purposes, I present the results from the baseline regressions with the added technological adaptation growth variables.

6.1 Descriptive Statistics for Baseline Regressions

This section presents the descriptive statistics for the baseline regressions I run while using labor productivity growth and total factor productivity as the dependent variables. Table 2 presents these statistics followed by discussion of the statistics.

Table 2: Descriptive Statistics for Baseline Regressions

Classifications with Labor Productivity as dependent: 26 countries (1980-2010)					
Variable	Obs	Mean	Std. Dev.	Min	Max
LPG	182	2.147	1.845	-7.252	9.734
RLG	160	4.787	3.173	-2.238	14.188
RDPG	155	3.641	3.242	-2.215	13.128
BERD	171	1.134	0.687	0.035	2.944
GERD	171	1.810	0.840	0.155	4.045
HERD	171	0.410	0.178	0.009	0.932
GOVERD	171	0.245	0.131	0.022	0.674
EDU	182	9.254	2.170	3.550	13.090

Classifications with Total Factor Productivity as dependent: 26 Countries (1990-2010)					
Variable	Obs	Mean	Std. Dev.	Min	Max
TFP	130	0.322	1.543	-4.160	9.980
RLG	122	4.689	3.411	-2.238	14.188
RDPG	118	3.723	3.489	-2.215	13.128
BERD	127	1.222	0.694	0.072	2.944
GERD	127	1.924	0.838	0.320	4.045
HERD	127	0.447	0.171	0.009	0.932
GOVERD	127	0.237	0.129	0.022	0.674
EDU	130	9.665	1.930	5.010	13.090

*All variables appear in percent form

In Table 2 one can see the considerable variation in LPG across countries, ranging from -7.25% in Greece (2010-2012) to 9.73% in South Korea (1985-1989) with a standard deviation of just under 2%. RLG and RDPG also show substantial variation, ranging from -2% to 13% with standard deviations of around 3%. The variables BERD, GERD, HERD and GOVERD have a smaller variation than the other variables and consequently the standard deviation for these variables is low. These variables capture R&D expenditure as a percent of GDP, and as so the smaller variation and low standard deviation is normal. The variable EDU has considerable variation from 3.55 years of education in Luxembourg (1980) to 13.09 years of education in New Zealand (2010) and the United States (2010).

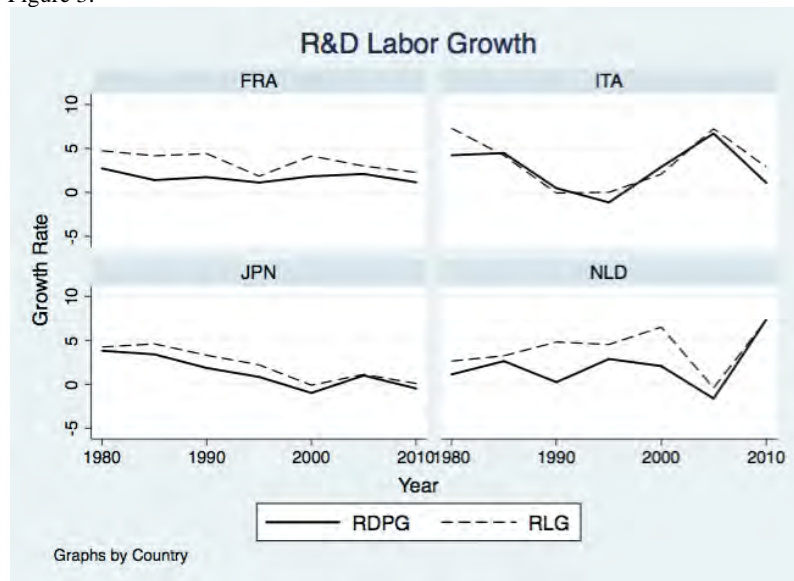
Table: 3

Average Standard Deviations for the Baseline Classifications							
LPG	RDPG	RLG	BERD	GERD	HERD	GOVERD	EDU
1.409	2.577	2.662	0.282	0.365	0.107	0.054	0.925
TFP	RDPG	RLG	BERD	GERD	HERD	GOVERD	EDU
1.087	2.615	2.705	0.232	0.291	0.084	0.045	0.672

The second part of Table 2 presents the descriptive statistics for the regression classifications I test while using total factor productivity as the dependent variable. The independent variables used in this classification are the same as those used with the labor productivity growth classifications. As can be seen, the standard deviation for most independent variables drops because of the shortened time horizon in TFP regressions. TFP growth ranges from -4.16% in Greece (2010-2013) to 9.98% in Iceland (2010-2013) and has a standard deviation of 1.5%.

Table 3 shows the average standard deviations for variables used in the baseline regressions. These standard deviations differ from those in Table 2 as they are the average of all the individual country standard deviations, and so give a better interpretation of the data than when looking at it as a whole.¹⁰ Figures 3-7 present the data in graphic form in order to clearly see the cross-country trends that exist.

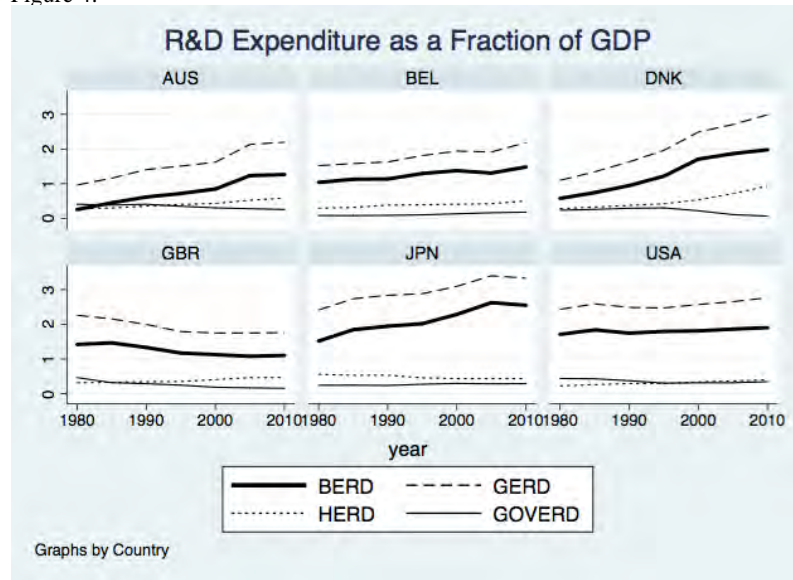
Figure 3:



Note: R&D Personnel (RDPG) is the growth in researchers, technicians, and other support staff engaged in R&D. Researchers (RLG) is comprised of the labor growth of those engaged in the creation of new knowledge, products, processes,

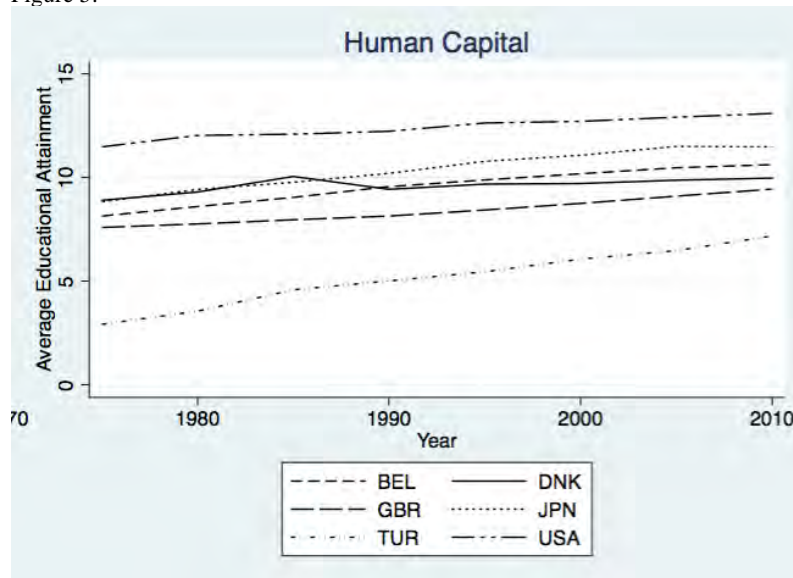
¹⁰ Individual country standard deviations for the baseline classifications are available in the appendix.

Figure 4:



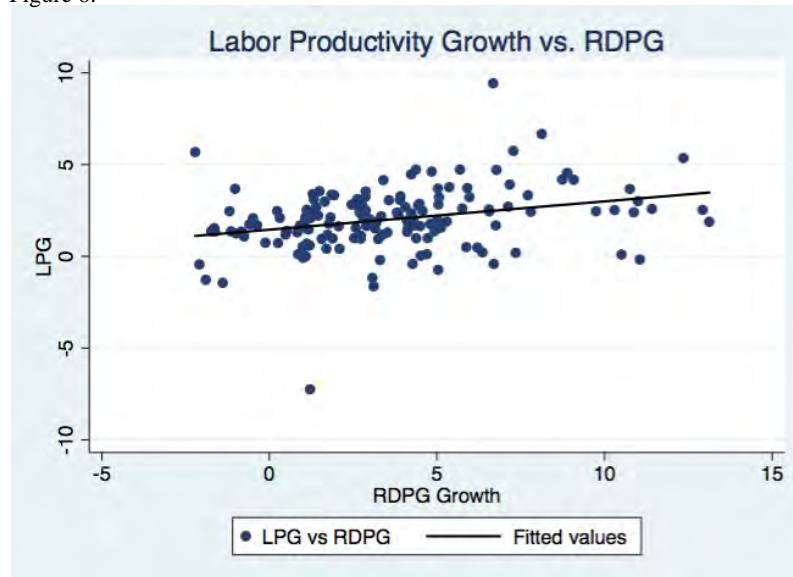
Note: BERD is business enterprise expenditure on R&D as a percent of GDP. GERD is gross expenditure on R&D as a percent of GDP. HERD is the expenditure on R&D in higher education as a percent of GDP, and GOVERD is the government expenditure on R&D as a percent of GDP.

Figure 5:



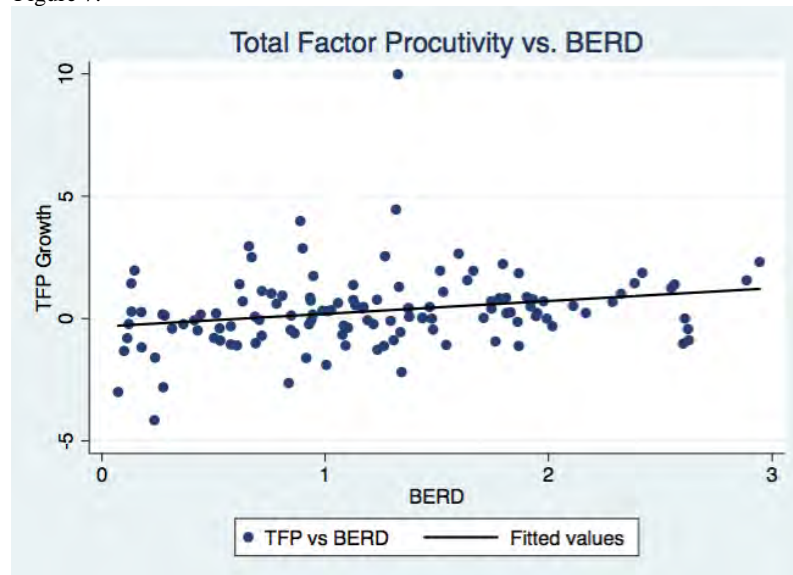
Note: Human Capital is measured as the average education of individuals aged over 15, measured in years.

Figure 6:



Note: Labor Productivity Growth (LPG) is calculated as GDP per capita / total hours worked per capita on a yearly basis. R&D Personnel (RDPG) is the growth in researchers, technicians, and other support staff engaged in R&D.

Figure 7:



Note: Total Factor Productivity (TFP) is the annual growth rate calculated as Tornqvist index. BERD is business enterprise expenditure on R&D as a percent of GDP.

6.2 Baseline Regression Results

In this section I present the regression results from the baseline tests I run. I will first show the results under the semi-endogenous and fully endogenous theories using labor productivity growth as the dependent variable. Following these I will present the results while using total factor productivity growth as the dependent variable.

Table 4 shows the results from the baseline regressions under the semi-endogenous classification. Columns (1) and (3) respectively test the broad and narrow R&D labor variables against LPG. Columns (2) and (4) add a human capital variable to the regressions. All four regressions presented in Table 4

Table 4:

Impact of R&D Input Growth on Labor Productivity Growth				
Dependent Variable	Labor Productivity Growth from country <i>c</i> at time <i>t</i>			
Sample Coverage	1980-2010 (with gaps), 26 Countries			
	(1)	(2)	(3)	(4)
	Broad Labor Definition	Broad Labor Definition with EDU	Narrow Labor Definition	Narrow Labor Definition with EDU
RDPG	0.173*** (0.0631)	0.174*** (0.0633)		
EDU		-0.318 (0.639)		-0.343 (0.633)
RLG			0.173*** (0.0567)	0.174*** (0.0569)
Year Fixed Effects	Y	Y	Y	Y
Country Fixed Effects	Y	Y	Y	Y
Country Specific Time Trends	Y	Y	Y	Y
N	155	155	160	160
R-sq	0.338	0.339	0.348	0.349
adj. R-sq	0.019	0.012	0.030	0.024

Standard errors in parentheses

=** p<0.10

** p<0.05

*** p<0.01"

Note: Labor Productivity Growth (LPG) is calculated as GDP per capita / total hours worked per capita on a yearly basis. RDPG is the growth in researchers, technicians, and other support staff engaged in R&D. RLG is comprised of the labor growth of those engaged in the creation of new knowledge, products, processes, methods, and systems. EDU is the average education of individuals aged over 15, measured in years.

control for time and country variations as well as controlling for country specific time trends. As can be seen the coefficients for RDPG and RLG are significant at the 1% level and are positive. To interpret these coefficients I assume there is one standard deviation change of 2.5% in RDPG or RLG, which will positively impact labor productivity growth by 0.4%.¹¹ The small change in the coefficients of RDPG and RLG when I add the EDU variable shows that the R&D labor variables are robust. The R^2 of .34 shows that the regressions explain 34% of the variation that exists. The results in Table 4 reject the null hypothesis that the impact of R&D labor growth on LPG significantly differs from zero, giving support to the semi-endogenous theory.

Table 5 presents the results from the baseline regressions I run under the fully endogenous classification. Columns (1), (3), and (5) respectively test the impact of business expenditure, gross expenditure, and business, higher education, and government expenditure on labor productivity growth. To avoid multicollinearity I do not test GERD

¹¹ Note that the standard deviation used for the magnitude test is from the average of all countries standard deviation, Table 3.

Table 5:

Impact of R&D Input Fraction on Labor Productivity Growth						
Dependent Variable	Labor Productivity Growth from country <i>c</i> at time <i>t</i>					
Sample Coverage	1980-2010 (with gaps), 26 Countries					
	(1)	(2)	(3)	(4)	(5)	(6)
	Business- Expenditure	Business Expenditure and EDU	Gross Expenditure	Gross Expenditure and EDU	Business, Higher Edu, and Government	Business, Higher Edu, and Government Expenditure and EDU
BERD	1.692* (1.019)	1.678 (1.044)			2.014* (1.040)	1.997* (1.064)
EDU		-0.0426 (0.654)		-0.0615 (0.659)		-0.0549 (0.653)
GERD			1.216 (0.860)	1.201 (0.877)		
HERD					0.673 (4.051)	0.659 (4.072)
GOVERD					-6.088 (3.758)	-6.094 (3.775)
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Country Fixed Effects	Y	Y	Y	Y	Y	Y
Country Specific Time Trends	Y	Y	Y	Y	Y	Y
N	171	171	171	171	171	171
R-sq	0.259	0.259	0.254	0.254	0.276	0.276
adj. R-sq	-0.068	-0.077	-0.075	-0.084	-0.061	-0.070

Standard errors in parentheses

="* p<0.10

** p<0.05

*** p<0.01"

Note: LPG is calculated as GDP per capita / total hours worked per capita on a yearly basis. BERD is business enterprise expenditure on R&D as a percent of GDP. GERD is gross expenditure on R&D as a percent of GDP. HERD is the expenditure on R&D in higher education as a percent of GDP, and GOVERD is the government expenditure on R&D as a percent of GDP. EDU is the average education of individuals aged over 15, measured in years.

in the same regressions with the other three measurements of R&D expenditure because GERD is inclusive of the other measurements. Columns (2), (4), and (6) add a human capital variable to the regression. All six regressions presented in Table 5 control for time and country variations, while also controlling for country specific time trends. BERD is marginally significant in (1), (5), and (6) showing the positive relationship that exists between R&D expenditure and labor productivity growth. A one standard deviation change of 0.28% in BERD would result in labor productivity growth of 0.5%.¹² The R² of .25 shows that the regressions account for 25% of the variation that exists. The small coefficient change in BERD from column (1) and (2), and (5) and (6)

¹² Note that the standard deviation used for the magnitude is taken from Table 3.

Table 6:

Impact of R&D Input Growth on Total Factor Productivity Growth				
Dependent Variable	Total Factor Productivity from country <i>c</i> at time <i>t</i>			
Sample Coverage	1990-2010 (with gaps), 26 Countries			
	(1)	(2)	(3)	(4)
	Broad Labor	Broad Labor	Narrow Labor	Narrow Labor
	Definition	Definition with EDU	Definition	Definition with EDU
RDPG	-0.00385 (0.0516)	0.0107 (0.0523)		
EDU		-0.904 (0.641)		-0.947 (0.629)
RLG			0.0283 (0.0489)	0.0416 (0.0492)
Year Fixed Effects	Y	Y	Y	Y
Country Fixed Effects	Y	Y	Y	Y
Country Specific Time Trends	Y	Y	Y	Y
N	118	118	122	122
R-sq	0.400	0.417	0.398	0.418
adj. R-sq	-0.048	-0.033	-0.055	-0.036
Standard errors in parentheses				
="* p<0.10 ** p<0.05 *** p<0.01"				

Note: Total Factor Productivity (TFP) is the annual growth rate calculated as Tornqvist index. RDPG is the growth in researchers, technicians, and other support staff engaged in R&D. RLG is comprised of the labor growth of those engaged in the creation of new knowledge, products, processes, methods, and systems. EDU is the average education of individuals aged over 15, measured in years.

shows that the variable is robust. I can marginally reject the null hypothesis that R&D expenditure's impact on LPG is significantly different from zero.

Table 6 presents the baseline regressions under the semi-endogenous framework while using total factor productivity growth as the dependent variable. Columns (1) and (3) respectively test the broad and narrow R&D labor definitions against TFP. Columns (2) and (4) add a human capital variable to the regression. All four regressions presented in Table 6 control for time and country variations while also accounting for country specific time trends. As can be seen there are no significant results and the null hypothesis cannot be rejected. The R^2 of .4 shows that the regressions account for 40% of the variation that exists.

Table 7:

Impact of R&D Input Fraction on Total Factor Productivity Growth						
Dependent Variable	Total Factor Productivity Growth from country <i>c</i> at time <i>t</i>					
Sample Coverage	1990-2010 (with gaps), 26 Countries					
	(1)	(2)	(3)	(4)	(5)	(6)
	Business Expenditure	Business Expenditure and EDU	Gross Expenditure	Gross Expenditure and EDU	Business, Higher Edu, and Government	Business, Higher Edu, and Government Expenditure and EDU
BERD	-1.457 (0.943)	-1.461 (0.941)			-0.778 (1.007)	-0.679 (1.001)
EDU		-0.756 (0.664)		-0.821 (0.665)		-0.963 (0.668)
GERD			-1.277 (0.774)	-1.306* (0.772)		
HERD					2.399 (3.909)	1.691 (3.911)
GOVERD					-9.136* (4.812)	-10.28** (4.842)
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Country Fixed Effects	Y	Y	Y	Y	Y	Y
Country Specific Time Trends	Y	Y	Y	Y	Y	Y
N	127	127	127	127	127	127
R-sq	0.489	0.498	0.492	0.502	0.515	0.528
adj. R-sq	0.130	0.133	0.135	0.141	0.150	0.163

Standard errors in parentheses

="* p<0.10 ** p<0.05 *** p<0.01"

Note: Total Factor Productivity (TFP) is the annual growth rate calculated as Tornqvist index. BERD is business enterprise expenditure on R&D as a percent of GDP. GERD is gross expenditure on R&D as a percent of GDP. HERD is the expenditure on R&D in higher education as a percent of GDP, and GOVERD is the government expenditure on R&D as a percent of GDP. EDU is the average education of individuals aged over 15, measured in years.

Table 7 presents the results of the regressions I run under the fully endogenous framework while using total factor productivity growth as the dependent variable. Columns (1), (3) and (5) respectively test the impact of business expenditure, gross expenditure, and business, higher education and government expenditure on total factor productivity growth. To avoid multicollinearity issues I do not test GERD with any other expenditure variables. Columns (2), (4) and (5) add a human capital variable to the regressions. All six regressions presented in Table 7 control for time and country variations while also accounting for country specific time trends. As can be seen GERD and GOVERD are marginally significant in columns (4) – (6). The coefficients for GERD and GOVERD are negative, implying that increasing the fraction of resources to

gross R&D expenditure or governmental expenditure will decrease the growth of TFP. It is worthwhile to notice that GERD is not significant in (4) but is marginally significant when the human capital variable is added, showing the importance of human capital for productivity growth. The R^2 of 0.5 implies that the regressions account for 50% of the variation that exists. The null hypothesis that R&D expenditure variables impact on TFP growth significantly differs from zero cannot be rejected.

In conclusion, the baseline regressions testing the semi and fully endogenous theories only reject the null hypothesis when labor productivity growth is utilized as the dependent variable. While using LPG as the dependent variable, the semi-endogenous framework strongly rejects the null hypothesis and the fully endogenous framework marginally rejects the null.

6.3 Descriptive Statistics for Baseline Regressions with added Technological Adaptation Growth Variables

This section will present the descriptive statistics for the regressions I run with the added technological adaptation growth variables. Table 8 presents these statistics. In order to avoid repetition, this section will focus on the technological adaptation growth variables. Refer to Table 2 and the discussion that follows for all other variables. The three variables I focus on in this section are cell phone unit growth (CELL), personal computer unit growth (PC), and Internet access growth (INTERNET).

The data presented in the first section of Table 8 shows the descriptive statistics for the regression classifications using labor productivity growth as the dependent variable. The variation for CELL is vast, ranging from 9.1% growth in South Korea (2000-2003) to 76.2% growth in Australia (1987-1989) with a standard deviation of 15%. PC also has a wide variation, ranging from 2.9% growth in Luxembourg (1995-2000) to 48.3% growth in South Korea (1985-1990) with a standard deviation of 7%. In

Table 8: Descriptive Statistics for Regressions with Technological Adaptation
Classifications with Labor Productivity as dependent: 26 Countries (1985-2000)

Variable	Obs	Mean	Std. Dev.	Min	Max
LPG	104	2.653	1.760	-1.635	9.734
RLG	92	5.274	3.185	-0.110	14.188
RDPG	90	3.816	3.309	-2.215	12.932
BERD	97	1.075	0.653	0.072	2.885
GERD	98	1.732	0.795	0.282	3.836
HERD	97	0.383	0.155	0.009	0.819
GOVERD	97	0.248	0.135	0.028	0.674
EDU	104	9.044	2.054	4.580	12.710
CELL	102	33.646	15.414	9.128	76.283
PC	98	15.981	7.383	2.963	48.338
INTERNET	78	34.900	16.980	-5.312	83.343

Classifications with Total Factor Productivity as dependent: 26 countries (1990-2000)

Variable	Obs	Mean	Std. Dev.	Min	Max
TFP	78	0.612	1.099	-3.006	3.982
RLD	73	5.194	3.321	-0.110	14.188
RDPG	71	3.819	3.535	-2.215	12.932
BERD	75	1.107	0.656	0.072	2.885
GERD	76	1.777	0.793	0.320	3.836
HERD	75	0.401	0.150	0.009	0.819
GOVERD	75	0.243	0.137	0.028	0.674
EDU	78	9.253	1.946	5.010	12.710
CELL	78	29.254	12.533	9.128	68.621
PC	77	13.502	4.830	2.963	29.978
INTERNET	78	34.900	16.980	-5.312	83.343

*All variables appear in percent form

addition, INTERNET also has a large variation, ranging from -5.3% growth in Norway (2000-2003) to 83.3% growth in Turkey (1990-1995) with a standard deviation of 17%.

The second section of Table 8 presents the descriptive statistics for the regression classifications that utilize total factor productivity growth as the dependent

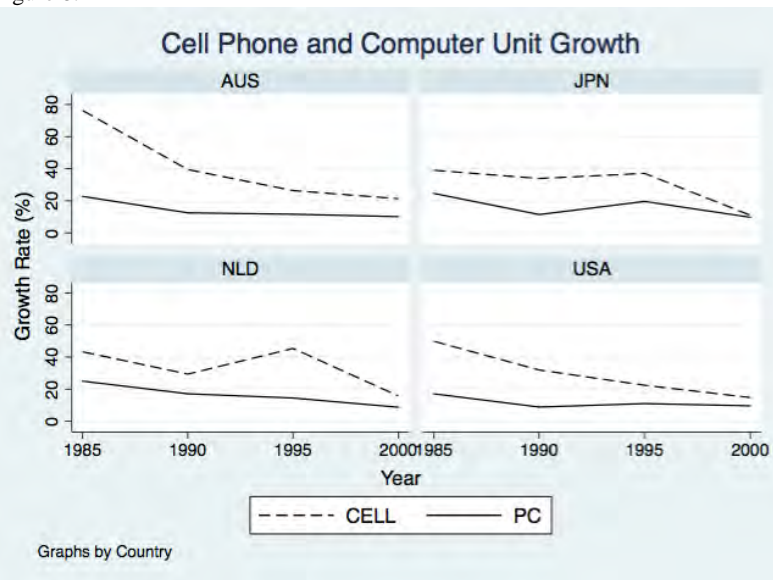
variable. The time horizon while using TFP as the dependent variable is smaller when using LPG. As a result the standard deviation decreases for CELL and PC but remains unchanged for INTERNET.

Table 9:
Average Standard Deviations for the Baseline Classifications with Technological Adaptation Growth Variables

LPG	RDPG	RLG	BERD	GERD	HERD	GOVERD	EDU	CELL	PC	INTERNET
1.248	2.204	2.502	0.196	0.243	0.065	0.037	0.584	14.949	6.554	18.018
TFP	RDPG	RLG	BERD	GERD	HERD	GOVERD	EDU	CELL	PC	INTERNET
0.751	2.261	2.410	0.174	0.208	0.046	0.033	0.450	11.823	3.955	18.018

Table 9 shows the average standard deviations of the variables I use for these classification of regressions. These standard deviations differ from those in Table 8 because they are the average of the individual country standard deviations, and so give a better interpretation of the data than when looking at it as a whole.¹³ Figures 8 and 9 below illustrate these statistics in graphical form.

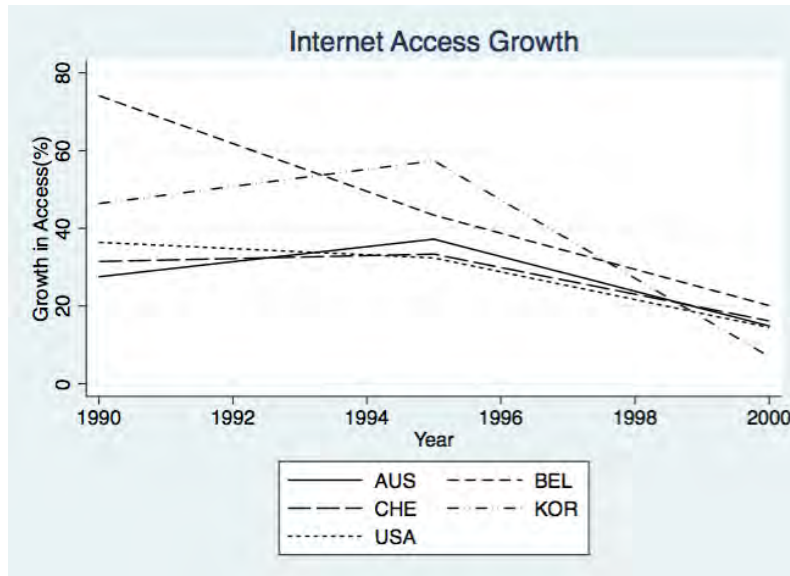
Figure 8:



Note: CELL is the unit growth of cell phones. PC is the unit growth of personal computers.

¹³ The standard deviations for each country appear in the appendix.

Figure 9:



Note: Internet Access (INTERNET) is measured as the growth in individual access to the Internet.

6.4 Baseline Regression Results with added Technological Adaptation Growth Variables

In this section I present the regression results from the baseline regressions I run with added technological adaptation growth variables. I will first show the results under the semi-endogenous and fully endogenous theories while using labor productivity growth as the dependent variable. Following these I will present the results while utilizing total factor productivity growth as the dependent variable.

Table 10:

Impact of R&D Input Growth and Tech Unit Growth on Labor Productivity Growth				
Dependent Variable	Labor Productivity Growth from country <i>c</i> at time <i>t</i>			
Sample Coverage	1985-2000 (with gaps), 26 Countries			
	(1)	(2)	(3)	(4)
	Broad Labor Definition with Tech Unit Growth	Broad Labor Definition with Tech Unit Growth and EDU	Narrow Labor Definition with Tech Unit Growth	Narrow Labor Definition with Tech Unit Growth and EDU
RDPG	0.111 (0.110)	0.107 (0.113)		
CELL	0.0447* (0.0245)	0.0464* (0.0256)	0.0476** (0.0227)	0.0478* (0.0237)
PC	0.0671 (0.0909)	0.0806 (0.102)	0.0789 (0.0922)	0.0808 (0.106)
INTERNET	0.0414 (0.0264)	0.0417 (0.0270)	0.0404 (0.0274)	0.0403 (0.0282)
EDU		-1.076 (3.310)		-0.131 (3.331)
RLG			0.102 (0.0944)	0.101 (0.0972)
Year Fixed Effects	Y	Y	Y	Y
Country Fixed Effects	Y	Y	Y	Y
Country Specific Time Trends	Y	Y	Y	Y
N	71	71	73	73
R-sq	0.786	0.787	0.790	0.790
adj. R-sq	0.167	0.123	0.162	0.112
Standard errors in parentheses				
="* p<0.10 ** p<0.05 *** p<0.01"				

Note: Labor Productivity Growth (LPG) is calculated as GDP per capita / total hours worked per capita on a yearly basis. RDPG is the growth in researchers, technicians, and other support staff engaged in R&D. RLG is comprised of the labor growth of those engaged in the creation of new knowledge, products, processes, methods, and systems. EDU is the average education of individuals aged over 15, measured in years. CELL is the unit growth of cell phones. PC is the unit growth of personal computers. INTERNET is the growth in individual access to the Internet.

Table 10 shows the results from the regressions I run under the semi-endogenous framework with technological adaptation variables and using LPG as the dependent variable. Columns (1) and (3) respectively test the broad and narrow R&D labor variables with technological adaptation variables against LPG. Columns (2) and (4) add a human capital variable to the specifications of (1) and (3). All four regressions presented in Table 10 control for time and country variations as well as controlling for country specific time trends. CELL for all four regressions is marginally significant and

positive. A one standard deviation change in CELL of 15% implies that LPG will increase by 0.7%.¹⁴ The R^2 of just under 0.80 is high and shows that the regressions can explain 80% of the variation that exists. These results show that the null hypothesis can be rejected for CELL, but it is not rejected for the other variables meaning that the impact of R&D labor on LPG is not significantly different from zero.

Table 11 shows the results from the regressions I run under the fully endogenous framework with technological adaptation variables and using LPG as the dependent variable. Columns (1), (3) and (5) respectively test business expenditure, gross expenditure, and business, higher education, and government expenditure all with technological adaptation variables. Columns (2), (4), and (6) add a human capital variable to the specifications of (1), (3) and (5). All six regressions presented in Table 11 control for time and country variations as well as controlling for country specific time trends. BERD is marginally significant in (1) and (2) and is significant at the 5% level in (5) and (6). Under the specifications in column (5), a one standard deviation change of 0.2% in BERD would result in LPG growth of 1.7%.¹⁵ BERD in (1) has a coefficient of 6.7 and in (6) the coefficient jumps to 10.7 showing that the variable is not robust. CELL is significant at the 1% level in (1), and significant at the 5% level

¹⁴ Note that the standard deviation used for the magnitude test is taken from Table 9.

¹⁵ Note that the standard deviation used for the magnitude test is taken from Table 9.

Table 11:
Impact of R&D Input Fraction and Tech Unit Growth on Labor Productivity Growth

Dependent Variable	Labor Productivity Growth from country <i>c</i> at time <i>t</i>					
Sample Coverage	1985-2000 (with gaps), 26 Countries					
	(1)	(2)	(3)	(4)	(5)	(6)
	Business Expenditure and Tech Unit Growth	Business Expenditure, Tech Unit Growth, and EDU	Gross Expenditure and Tech Unit Growth	Gross Expenditure, Tech Unit Growth and EDU	Business, Higher Edu, and Government Expenditure and Tech Unit Growth	Business, Higher Edu, and Government Expenditure and Tech Unit Growth and EDU
BERD	6.784* (3.401)	7.541* (3.663)			8.504** (3.714)	10.72** (4.130)
CELL	0.0606*** (0.0212)	0.0589** (0.0217)	0.0541** (0.0233)	0.0523** (0.0238)	0.0611** (0.0218)	0.0567** (0.0219)
PC	0.0106 (0.0845)	-0.0160 (0.0959)	0.113 (0.0857)	0.0889 (0.0962)	0.0415 (0.0891)	-0.00281 (0.0959)
INTERNET	0.0456* (0.0252)	0.0457* (0.0256)	0.0195 (0.0247)	0.0200 (0.0251)	0.0562* (0.0270)	0.0597** (0.0268)
EDU		1.937 (3.122)		2.117 (3.545)		3.984 (3.388)
GERD			4.904 (3.777)	5.909 (4.189)		
HERD					10.22 (9.929)	12.34 (9.990)
GOVERD					11.32 (13.96)	18.49 (15.10)
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Country Fixed Effects	Y	Y	Y	Y	Y	Y
Country Specific Time Trends	Y	Y	Y	Y	Y	Y
N	75	75	76	76	75	75
R-sq	0.794	0.798	0.742	0.747	0.810	0.824
adj. R-sq	0.238	0.214	0.079	0.050	0.220	0.236

Standard errors in parentheses
 ==* p<0.10 ** p<0.05 *** p<0.01"

Note: Labor Productivity Growth (LPG) is calculated as GDP per capita / total hours worked per capita on a yearly basis. BERD is business enterprise expenditure on R&D as a percent of GDP. GERD is gross expenditure on R&D as a percent of GDP. HERD is the expenditure on R&D in higher education as a percent of GDP, and GOVERD is the government expenditure on R&D as a percent of GDP. EDU is the average education of individuals aged over 15, measured in years. CELL is the unit growth of cell phones. PC is the unit growth of personal computers. INTERNET is the growth in individual access to the Internet.

for (2) – (6). A one standard deviation change in CELL of 15%, under the specification of (5), would result in LPG growth of 0.9%.¹⁶ INTERNET is marginally significant in (1), (2) and (4) and is significant at the 5% level in (6). Interpreting the magnitude in (6) a one standard deviation change in INTERNET of 18% would result in LPG growth of 1%.¹⁷ The large R² of 0.8 shows that the regressions can explain 80% of the variation

¹⁶ Note that the standard deviation used for the magnitude test is taken from Table 9.

¹⁷ Note that the standard deviation used for the magnitude test is taken from Table 9.

that exists. In conclusion BERD's impact on LPG significantly differs from zero, meaning that the null hypothesis is rejected in support of the fully endogenous theory.

Table 12:
Impact of R&D Input Growth and Tech Unit Growth on Total Factor Productivity Growth

Dependent Variable	Labor Productivity Growth from country <i>c</i> at time <i>t</i>			
Sample Coverage	1990-2000 (with gaps), 26 Countries			
	(1)	(2)	(3)	(4)
	Broad Labor Definition with Tech Unit Growth	Broad Labor Definition with Tech Unit Growth and EDU	Narrow Labor Definition with Tech Unit Growth	Narrow Labor Definition with Tech Unit Growth and EDU
RDPG	0.0541 (0.0763)	0.0489 (0.0781)		
CELL	0.00779 (0.0170)	0.0101 (0.0177)	0.0102 (0.0159)	0.0118 (0.0165)
PC	-0.000266 (0.0633)	0.0177 (0.0705)	0.00147 (0.0646)	0.0184 (0.0740)
INTERNET	0.0182 (0.0183)	0.0186 (0.0187)	0.0178 (0.0192)	0.0174 (0.0196)
EDU		-1.436 (2.284)		-1.170 (2.315)
RLG			0.0364 (0.0661)	0.0354 (0.0675)
Year Fixed Effects	Y	Y	Y	Y
Country Fixed Effects	Y	Y	Y	Y
Country Specific Time Trends	Y	Y	Y	Y
N	71	71	73	73
R-sq	0.767	0.772	0.766	0.770
adj. R-sq	0.094	0.063	0.064	0.024

Standard errors in parentheses
 =** p<0.10 ** p<0.05 *** p<0.01"

Note: Total Factor Productivity (TFP) is the annual growth rate calculated as Tornqvist index. RDPG is the growth in researchers, technicians, and other support staff engaged in R&D. RLG is comprised of the labor growth of those engaged in the creation of new knowledge, products, processes, methods, and systems. EDU is the average education of individuals aged over 15, measured in years. CELL is the unit growth of cell phones. PC is the unit growth of personal computers. INTERNET is the growth in individual access to the Internet.

Figure 12 shows the results from the regressions I run under the semi-endogenous framework with the technological adaptation variables and using TFP growth as the dependent variable. Columns (1) and (3) respectively test the broad and narrow R&D labor variables with technological adaptation variables against TFP growth. Columns (2) and (4) then add a human capital variable to the specifications in (1) and (3). All four regressions presented in Table 12 control for time and country

variations as well as controlling for country specific time trends. The R^2 of 0.77 shows that the regressions explain 77% of the variation that exists. There are no significant results in Table 12 meaning that the null hypothesis cannot be rejected and the impact of the independent variables on TFP does not significantly differ from zero.

Table 13 shows the results from the regressions I run under the fully endogenous framework with the technological adaptation variables and using TFP growth as the dependent variable. Columns (1), (3) and (5) respectively test business expenditure, gross expenditure, and business, higher education, and government expenditure with technological adaptation variables. Columns (2), (4), and (6) add a human capital variable to the specifications of (1), (3) and (5). All six regressions presented in Table 13 control for time and country variations as well as controlling for country specific time trends. BERD is marginally significant in (1), (2) and (3) and is significant at the 5% level in (6). Interpreting the magnitude in (6) a one standard deviation change in BERD of 0.17% would result in TFP growth of 1.2%.¹⁸ The R^2 of about 0.7 implies that the regressions can explain 70% of the variation that exists. The null hypothesis can be rejected meaning that the impact of BERD upon TFP is significantly different from zero.

¹⁸ Note that the standard deviation used for the magnitude test is taken from Table 9.

Table 13:

Impact of R&D Input Fraction and Tech Unit Growth on Total Factor Productivity Growth

Dependent Variable	Labor Productivity Growth from country <i>c</i> at time <i>t</i>					
Sample Coverage	1990-2010 (with gaps), 26 Countries					
	(1)	(2)	(3)	(4)	(5)	(6)
	Business Expenditure and Tech Unit Growth	Business Expenditure, Tech Unit Growth, and EDU	Gross Expenditure and Tech Unit Growth	Gross Expenditure, Tech Unit Growth and EDU	Business, Higher Edu, and Government Expenditure and Tech Unit Growth	Business, Higher Edu, and Government Expenditure and Tech Unit Growth and EDU
BERD	4.954* (2.712)	5.319* (2.941)			6.014* (3.008)	7.314** (3.409)
CELL	0.0189 (0.0169)	0.0181 (0.0174)	0.0165 (0.0169)	0.0154 (0.0173)	0.0182 (0.0176)	0.0157 (0.0181)
PC	-0.0642 (0.0674)	-0.0770 (0.0770)	-0.0134 (0.0621)	-0.0279 (0.0700)	-0.0465 (0.0722)	-0.0725 (0.0792)
INTERNET	0.0194 (0.0201)	0.0194 (0.0205)	0.0105 (0.0179)	0.0108 (0.0183)	0.0253 (0.0218)	0.0273 (0.0221)
EDU		0.936 (2.506)		1.248 (2.580)		2.338 (2.796)
GERD			4.476 (2.741)	5.068 (3.049)		
HERD					4.662 (8.041)	5.909 (8.245)
GOVERD					9.558 (11.31)	13.77 (12.47)
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Country Fixed Effects	Y	Y	Y	Y	Y	Y
Country Specific Time Trends	Y	Y	Y	Y	Y	Y
N	75	75	76	76	75	75
R-sq	0.703	0.705	0.686	0.689	0.718	0.729
adj. R-sq	-0.098	-0.147	-0.122	-0.164	-0.159	-0.179

Standard errors in parentheses

*** p<0.01

** p<0.05

*** p<0.01

Note: Total Factor Productivity (TFP) is the annual growth rate calculated as Tornqvist index. BERD is business enterprise expenditure on R&D as a percent of GDP. GERD is gross expenditure on R&D as a percent of GDP. HERD is the expenditure on R&D in higher education as a percent of GDP, and GOVERD is the government expenditure on R&D as a percent of GDP. EDU is the average education of individuals aged over 15, measured in years. CELL is the unit growth of cell phones. PC is the unit growth of personal computers. INTERNET is the growth in individual access to the Internet.

In conclusion the regressions I run while adding technological adaptation variables only reject the null hypothesis under the fully endogenous theory. The fully endogenous classifications reject the null while utilizing both LPG and TFP growth as the dependent variables.

7.0 Conclusions

My paper empirically assesses the responsiveness of technological change, measured as labor productivity growth and total factor productivity growth, to R&D inputs. In order to do so, I tested the responsiveness under Schumpeterian (R&D

induced) growth, specifically the semi and fully endogenous theories. The semi-endogenous theory predicts that there are diminishing returns to R&D due to the fact that R&D is becoming more difficult and as a result the average worker is becoming less productive. The fully endogenous theory predicts that there are diminishing returns to R&D due to a growing variety of products that are available in an economy. I run two specifications of regressions: the first one is the baseline framework that the theories discuss and the second one is the baseline framework with technological adaptation variables added.

Under the baseline framework I find strong support for the semi-endogenous framework and marginal support for the fully endogenous theory. However, this evidence is only significant when I use labor productivity growth as my dependent variable, when total factor productivity growth is used as the dependent the results are not significant. My evidence implies that the decreasing productivity growth despite increased resources allocated to R&D can be explained by decreasing returns to R&D. More specifically, this trend is better explained by the fact that R&D is becoming more difficult and that the average worker is becoming less productive, which is what semi-endogenous theory predicts.

The second specifications I run while using the technological adaptation parameters I find evidence in support of the fully endogenous theory. Under this specification I find no support of the semi-endogenous theory. For the fully endogenous framework I find significant evidence while using both labor productivity growth and total factor productivity growth as the dependent variables. This evidence implies that

the trends in the data can be explained by diminishing returns to R&D because of a growing product variety.

The evidence I find confirms and diverges from the findings of past literature. Zachariadis (2004) finds evidence in support of the fully endogenous theory and against the semi-endogenous theory; Madsen (2007) finds evidence against both the semi and fully endogenous theories, and Venturini (2012) finds evidence in support of the fully endogenous theory. The evidence I find with regard to the fully endogenous theory is in line with Zachariadis (2004) and Venturini (2012). The support I find for the semi-endogenous theory differs from all these papers, as they do not find any evidence, whereas I find strong support of the theory in my baseline regressions.

It is worthwhile to note that here are some limitations to my data that leaves room for improvement in the future. The measurement I use for total factor productivity growth has limitations that are worthwhile to point out. The time horizon for TFP growth data is less than that of LPG and so fewer observations is a possible reason for my TFP results being insignificant in the baseline regressions. In addition it would be beneficial to create the TFP growth variable using the raw data, whereas I used growth that was calculated by the *Conference Board*.

The semi-endogenous theory predicts that the way to maintain a balanced growth rate is to increase population growth, which by assumption is something that government policy cannot directly influence. The fully endogenous theory predicts that the way to maintain a balanced growth path is to maintain a constant fraction of resources to R&D and through increasing that fraction higher growth would ensue, which by assumption is something that government policy can directly influence. The

answer to the question of can policy spur technological growth is an ambivalent one. I find evidence that policy can directly impact the technological growth rate and evidence that policy cannot impact that growth. Evidence under my first specifications of regressions finds overwhelming support that policy cannot influence technological change, while the second specifications of regressions I run supports the idea that policy can have an impact on technological change.

Further questions remain to be explored in the context of Schumpeterian growth and policy's impact on technological change. A data set that encompasses a longer time horizon would be beneficial in answering which Schumpeterian theory can best explain the data trends. In addition, it is still a matter of debate over which indicators best tracks technological change, and so research that utilizes both productivity growth and patents as proxy's for technological change could give new incites into the different generations of Schumpeterian theory. My use of technological adaptation variables in my analysis forged a path for future literature to expand upon through longer time horizons and other technological adaptation variables. An interesting avenue for future research to pursue would be to compare countries at different stages of development. Most of the current literature uses very developed countries in their analysis. Comparing under-developed, developing, and developed countries could be useful to determine the impact that R&D has on innovational growth and if policy can influence that growth.

Appendix A: Further Data Discussion:

Countries Used (alphabetically by country code): Australia (AUS), Austria (AUT), Belgium (BEL), Canada (CAN), Switzerland (CHE), Germany (DEU), Denmark (DNK), Spain (ESP), Finland (FIN), France (FRA), United Kingdom (GBR), Greece (GRC), Ireland (IRL), Iceland (ISL), Italy (ITA), Japan (JPN), South Korea (KOR), Luxembourg (LUX), Netherlands (NLD), Norway (NOR), New Zealand (NZL), Portugal (PRT), Singapore (SGP), Sweden (SWE), Turkey (TUR), the United States (USA).

Labor Productivity Growth: calculated by dividing GDP per capita in 1990 US\$ (converted at Geary Khamis PPPs) by Annual hours worked per worker giving the hourly per capita output. The data for this calculation was taken from the *Conference Board's Total Economy Database – Output, Labor, and Labor Productivity, 1950-2013*.

Total Factor Productivity: estimated as Tornqvist index and was taken from the *Conference Board's Total Economy Database- Growth Accounting and Total Factor Productivity, 1990-2013*. For further exploration of the data you can find the datasets at the following link, <http://www.conference-board.org/data/economydatabase/>.

Total R&D Personnel: the annual growth rate of R&D personnel. The Main Science and Technology Indicators data is taken from OECD.StatExtracts and can be found under the theme of Science, Technology and Patents, in the subsection Science and Technology Indicators. For further exploration of the data follow the link, <http://stats.oecd.org/Index.aspx?QueryId=33210>. For more description how Total R&D Personnel is gathered by the OECD see: *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development*, which can be found at http://www.tubitak.gov.tr/tubitak_content_files/BTYPD/kilavuzlar/Frascati.pdf.

Total Researchers: the annual growth rate of researchers. The Main Science and Technology Indicators data is taken from OECD.StatExtracts and can be found under the theme of Science, Technology and Patents, in the subsection Science and Technology Indicators. For further exploration of the data follow the link, <http://stats.oecd.org/Index.aspx?QueryId=33210>. For more description how Total Researchers is gathered by the OECD see: *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development*, which can be found at http://www.tubitak.gov.tr/tubitak_content_files/BTYPD/kilavuzlar/Frascati.pdf.

BERD: Business enterprise expenditure on R&D as a fraction of GDP. The Main Science and Technology Indicators data is taken from OECD.StatExtracts and can be

found under the theme of Science, Technology and Patents, in the subsection Science and Technology Indicators. For further exploration of the data follow the link, <http://stats.oecd.org/Index.aspx?QueryId=33210>. For more description how BERD is gathered by the OECD see: *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development*, which can be found at http://www.tubitak.gov.tr/tubitak_content_files/BTYPD/kilavuzlar/Frascati.pdf.

GERD: Gross expenditure on R&D in a given year as a fraction of GDP. The Main Science and Technology Indicators data is taken from OECD.StatExtracts and can be found under the theme of Science, Technology and Patents, in the subsection Science and Technology Indicators. For further exploration of the data follow the link, <http://stats.oecd.org/Index.aspx?QueryId=33210>. For more description how GERD is gathered by the OECD see: *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development*, which can be found at http://www.tubitak.gov.tr/tubitak_content_files/BTYPD/kilavuzlar/Frascati.pdf.

GOVERD: Government expenditure on R&D as a fraction of GDP. GOVERD is the federal government and state/provincial (when significant) expenditure on R&D during a given year. The Main Science and Technology Indicators data is taken from OECD.StatExtracts and can be found under the theme of Science, Technology and Patents, in the subsection Science and Technology Indicators. For further exploration of the data follow the link, <http://stats.oecd.org/Index.aspx?QueryId=33210>. For more description how GOVERD is gathered by the OECD see: *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development*, which can be found at http://www.tubitak.gov.tr/tubitak_content_files/BTYPD/kilavuzlar/Frascati.pdf.

HERD: Higher education expenditure on R&D as a fraction of GDP. HERD is comprised mostly of general university funds (GUF) and external funds devoted to R&D within higher education institutions. The Main Science and Technology Indicators data is taken from OECD.StatExtracts and can be found under the theme of Science, Technology and Patents, in the subsection Science and Technology Indicators. For further exploration of the data follow the link, <http://stats.oecd.org/Index.aspx?QueryId=33210>. For more description how HERD is gathered by the OECD see: *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development*, which can be found at http://www.tubitak.gov.tr/tubitak_content_files/BTYPD/kilavuzlar/Frascati.pdf.

Educational Attainment: The Barro-Lee Educational Attainment data that I use is the average educational attainment for total population aged 15 and over, with observations taken every 5 years. The full data set can be found at, <http://www.barrolee.com/>.

Cellphone: is the unit growth of cell phones, year over year. The raw data for cell phone units can be found at <http://www.nber.org/papers/w15319>.

Appendix B: Country Specific Standard Deviations:

Table 14:

Country Specific Standard Deviations: Baseline Classifications with Labor Productivity Growth as Dependent (1980-2010)								
Country	LPG	RDPG	RLG	BERD	GERD	HERD	GOVERD	EDU
AUS	0.858	1.781	2.211	0.378	0.462	0.113	0.062	0.211
AUT	0.526	1.559	2.450	0.523	0.647	0.123	0.017	0.846
BEL	0.658	1.365	1.380	0.157	0.237	0.069	0.040	0.746
CAN	0.893	2.579	1.655	0.192	0.263	0.144	0.059	0.869
CHE	0.872	2.668	2.478	0.214	0.258	0.140	0.045	1.713
DEU	0.488	1.144	1.076	0.152	0.208	0.047	0.035	2.521
DNK	0.882	2.101	2.661	0.565	0.717	0.236	0.091	0.276
ESP	1.899	3.897	4.289	0.178	0.327	0.107	0.050	1.742
FIN	2.021	3.612	3.211	0.787	0.977	0.180	0.043	0.770
FRA	0.959	0.573	1.131	0.097	0.101	0.056	0.091	1.713
GBR	1.476	1.533	2.512	0.160	0.215	0.064	0.109	0.616
GRC	3.923	4.543	5.703	0.069	0.188	0.103	0.021	1.190
IRL	3.382	2.721	2.080	0.297	0.352	0.115	0.060	0.526
ISL	1.466	2.865	3.427	0.658	0.924	0.205	0.118	0.846
ITA	1.098	2.703	3.060	0.073	0.114	0.073	0.034	1.019
JPN	1.272	1.816	1.917	0.397	0.346	0.055	0.025	0.825
KOR	1.870	5.200	4.497	0.577	0.821	0.078	0.066	0.262
LUX	1.642	2.235	3.384	0.243	0.079	0.093	0.071	1.222
NLD	1.146	2.794	2.583	0.092	0.089	0.099	0.065	0.634
NOR	0.997	1.282	1.666	0.086	0.142	0.071	0.029	0.869
NZL	0.953	3.729	3.627	0.142	0.155	0.104	0.089	0.415
PRT	2.198	2.504	2.236	0.257	0.457	0.175	0.016	0.846
SGP	1.251	3.978	4.083	0.347	0.523	0.133	0.056	1.402
SWE	1.669	1.804	1.430	0.507	0.556	0.069	0.022	0.341
TUR	1.314	3.433	2.697	0.122	0.224	0.076	0.031	1.222
USA	0.931	..	1.761	0.067	0.116	0.060	0.055	0.415
Average	1.409	2.577	2.662	0.282	0.365	0.107	0.054	0.925

Note: Labor Productivity Growth (LPG) is calculated as GDP per capita / total hours worked per capita on a yearly basis. RDPG is the growth in researchers, technicians, and other support staff engaged in R&D. RLG is comprised of the labor growth of those engaged in the creation of new knowledge, products, processes, methods, and systems. EDU is the average education of individuals aged over 15, measured in years. BERD is business enterprise expenditure on R&D as a percent of GDP. GERD is gross expenditure on R&D as a percent of GDP. HERD is the expenditure on R&D in higher education as a percent of GDP, and GOVERD is the government expenditure on R&D as a percent of GDP.

Table 15:

Country Specific Standard Deviations: Baseline Classifications with Total Factor Productivity Growth as Dependent (1990-2010)								
Country	TFP	RDPG	RLG	BERD	GERD	HERD	GOVERD	EDU
AUS	1.238	1.541	1.520	0.298	0.367	0.092	0.060	0.202
AUT	0.371	1.718	2.425	0.459	0.572	0.087	0.013	0.592
BEL	0.540	1.367	1.500	0.127	0.203	0.048	0.039	0.432
CAN	0.524	3.123	1.809	0.135	0.174	0.105	0.040	0.783
CHE	0.569	2.668	2.478	0.174	0.153	0.092	0.028	1.199
DEU	0.496	1.366	0.915	0.155	0.235	0.051	0.037	1.664
DNK	1.070	2.421	3.039	0.443	0.552	0.230	0.107	0.206
ESP	0.448	4.225	4.572	0.138	0.245	0.063	0.051	1.474
FIN	1.262	3.990	3.662	0.599	0.701	0.135	0.036	0.696
FRA	0.400	0.434	1.122	0.043	0.072	0.045	0.077	1.199
GBR	0.808	1.130	2.963	0.101	0.106	0.059	0.056	0.517
GRC	1.809	4.543	5.703	0.051	0.114	0.059	0.020	0.901
IRL	2.141	0.939	1.596	0.185	0.257	0.093	0.013	0.424
ISL	4.046	3.512	4.376	0.549	0.686	0.149	0.097	0.494
ITA	0.683	2.996	2.985	0.073	0.095	0.045	0.030	0.695
JPN	0.702	1.159	1.441	0.305	0.255	0.043	0.023	0.542
KOR	0.218	5.200	4.497	0.577	0.821	0.078	0.066	0.150
LUX	1.200	2.235	3.384	0.243	0.079	0.093	0.071	0.851
NLD	0.338	3.375	3.006	0.055	0.066	0.063	0.062	0.343
NOR	2.033	1.443	1.433	0.043	0.033	0.037	0.027	0.783
NZL	0.423	3.986	3.627	0.135	0.131	0.048	0.051	0.324
PRT	1.158	2.914	2.340	0.273	0.435	0.154	0.020	0.494
SGP	2.275	3.978	4.083	0.347	0.523	0.133	0.056	0.969
SWE	1.036	1.668	1.526	0.337	0.350	0.062	0.024	0.359
TUR	2.044	3.433	2.697	0.122	0.224	0.076	0.031	0.851
USA	0.433	..	1.639	0.061	0.122	0.046	0.029	0.324
Average	1.087	2.615	2.705	0.232	0.291	0.084	0.045	0.672

Note: Total Factor Productivity (TFP) is the annual growth rate calculated as Tornqvist index. RDPG is the growth in researchers, technicians, and other support staff engaged in R&D. RLG is comprised of the labor growth of those engaged in the creation of new knowledge, products, processes, methods, and systems. EDU is the average education of individuals aged over 15, measured in years. BERD is business enterprise expenditure on R&D as a percent of GDP. GERD is gross expenditure on R&D as a percent of GDP. HERD is the expenditure on R&D in higher education as a percent of GDP, and GOVERD is the government expenditure on R&D as a percent of GDP.

Table 16:

Country Specific Standard Deviations: Technological Adaptation Classifications with Labor Productivity Growth as Dependent (1985-2000)											
Country	LPG	RDPG	RLG	BERD	GERD	HERD	GOVERD	EDU	CELL	PC	INTERNET
AUS	0.924	2.167	2.626	0.168	0.196	0.057	0.045	0.100	24.829	5.746	11.207
AUT	0.598	1.856	2.880	0.340	0.370	0.067	0.012	0.585	12.613	6.005	14.811
BEL	0.373	1.577	1.651	0.122	0.166	0.040	0.023	0.488	13.867	6.919	27.085
CAN	1.180	2.191	1.535	0.190	0.252	0.111	0.043	0.450	16.219	6.779	16.250
CHE	1.132	1.725	2.031	0.120	0.065	0.074	0.043	1.231	22.675	5.337	9.421
DEU	0.547	0.974	1.450	0.175	0.180	0.011	0.004	1.701	13.903	0.305	13.985
DNK	0.781	1.065	2.250	0.418	0.492	0.090	0.037	0.255	4.512	6.878	17.009
ESP	1.163	2.478	2.438	0.076	0.150	0.076	0.012	1.385	16.157	3.288	14.409
FIN	2.701	2.905	2.611	0.618	0.745	0.127	0.037	0.633	7.380	4.525	15.771
FRA	0.681	0.325	1.201	0.056	0.068	0.036	0.081	1.231	19.141	4.018	10.966
GBR	1.030	1.577	2.903	0.155	0.189	0.034	0.057	0.346	15.115	4.895	13.635
GRC	2.088	3.502	5.304	0.044	0.129	0.088	0.008	0.440	22.448	6.836	15.182
IRL	2.683	1.328	1.552	0.198	0.197	0.043	0.040	0.146	18.307	4.851	14.410
ISL	1.453	3.549	4.413	0.650	0.894	0.137	0.119	0.471	9.832	11.262	25.438
ITA	0.757	2.497	2.024	0.076	0.066	0.054	0.031	0.687	14.016	8.483	20.230
JPN	1.466	1.844	1.992	0.189	0.151	0.051	0.027	0.583	13.000	6.992	20.676
KOR	1.917	6.717	6.659	0.144	0.237	0.016	0.041	0.120	18.404	13.079	26.494
LUX	1.238	..	..	..	..	..	..	0.632	8.369	7.557	16.971
NLD	0.828	1.195	1.341	0.102	0.069	0.077	0.052	0.462	13.749	6.753	19.385
NOR	0.536	1.369	1.909	0.024	0.033	0.045	0.029	0.450	7.089	4.644	23.021
NZL	1.001	4.528	4.117	0.084	0.119	0.085	0.036	0.302	23.545	6.566	26.883
PRT	2.330	1.348	1.853	0.063	0.151	0.065	0.014	0.471	20.243	8.064	25.205
SGP	1.295	1.073	1.818	0.305	0.494	0.122	0.070	0.913	16.373	5.000	16.066
SWE	2.151	2.063	1.591	0.495	0.511	0.031	0.003	0.165	7.042	7.848	14.971
TUR	0.868	3.041	2.936	0.037	0.099	0.060	0.006	0.632	14.710	14.043	27.317
USA	0.720	..	1.472	0.039	0.059	0.032	0.058	0.302	15.133	3.737	11.657
Average	1.248	2.204	2.502	0.196	0.243	0.065	0.037	0.584	14.949	6.554	18.018

Note: Labor Productivity Growth (LPG) is calculated as GDP per capita / total hours worked per capita on a yearly basis. RDPG is the growth in researchers, technicians, and other support staff engaged in R&D. RLG is comprised of the labor growth of those engaged in the creation of new knowledge, products, processes, methods, and systems. EDU is the average education of individuals aged over 15, measured in years. CELL is the unit growth of cell phones. PC is the unit growth of personal computers. INTERNET is the growth in individual access to the Internet. BERD is business enterprise expenditure on R&D as a percent of GDP. GERD is gross expenditure on R&D as a percent of GDP. HERD is the expenditure on R&D in higher education as a percent of GDP, and GOVERD is the government expenditure on R&D as a percent of GDP.

Table 17:

Country Specific Standard Deviations: Technological Adaptation Classifications with Total Factor Productivity Growth as Dependent (1990-2000)											
Country	TFP	RDPG	RLG	BERD	GERD	HERD	GOVERD	EDU	CELL	PC	INTERNET
AUS	0.675	1.800	1.765	0.116	0.106	0.037	0.051	0.085	9.366	1.214	11.207
AUT	0.451	2.152	2.398	0.330	0.341	0.042	0.007	0.482	15.011	2.310	14.811
BEL	0.330	1.905	1.986	0.122	0.157	0.013	0.023	0.310	13.333	7.190	27.085
CAN	0.383	2.639	1.840	0.172	0.214	0.089	0.040	0.317	6.226	5.002	16.250
CHE	0.679	1.725	2.031	0.095	0.064	0.007	0.028	1.045	8.256	5.365	9.421
DEU	0.428	0.731	0.409	0.108	0.118	0.010	0.004	0.954	8.094	0.143	13.985
DNK	1.070	1.011	2.452	0.387	0.433	0.083	0.045	0.154	5.430	4.538	17.009
ESP	0.418	2.733	2.690	0.063	0.090	0.036	0.013	1.356	13.442	1.305	14.409
FIN	0.730	3.517	2.340	0.576	0.654	0.107	0.035	0.637	8.838	4.525	15.771
FRA	0.222	0.386	1.407	0.035	0.078	0.027	0.072	1.045	14.409	2.533	10.966
GBR	0.418	1.523	2.911	0.108	0.132	0.034	0.051	0.305	7.043	1.460	13.635
GRC	0.923	3.502	5.304	0.039	0.100	0.067	0.009	0.155	22.448	2.035	15.182
IRL	1.693	0.602	1.412	0.109	0.111	0.021	0.013	0.142	14.246	3.399	14.410
ISL	1.531	4.208	5.357	0.652	0.812	0.100	0.073	0.285	11.030	11.262	25.438
ITA	0.552	2.031	1.215	0.065	0.066	0.048	0.028	0.535	16.334	2.781	20.230
JPN	0.498	1.441	1.740	0.180	0.137	0.052	0.030	0.443	14.224	5.289	20.676
KOR	0.205	6.717	6.659	0.144	0.237	0.016	0.041	0.055	21.912	2.423	26.494
LUX	0.175							0.527	9.730	7.557	16.971
NLD	0.176	1.354	1.068	0.035	0.024	0.043	0.056	0.301	14.810	4.294	19.385
NOR	1.202	1.475	1.413	0.020	0.015	0.001	0.034	0.317	8.035	4.644	23.021
NZL	0.027	5.088	4.117	0.096	0.091	0.039	0.038	0.257	9.403	6.566	26.883
PRT	1.519	1.492	1.623	0.065	0.106	0.033	0.015	0.285	20.243	0.987	25.205
SGP	1.637	1.073	1.818	0.305	0.494	0.122	0.070	0.720	7.788	4.510	16.066
SWE	0.859	2.113	1.764	0.452	0.477	0.037	0.002	0.190	5.912	3.394	14.971
TUR	2.489	3.041	2.936	0.037	0.099	0.060	0.006	0.527	13.245	7.015	27.317
USA	0.242		1.607	0.034	0.053	0.026	0.038	0.257	8.597	1.087	11.657
Average	0.751	2.261	2.410	0.174	0.208	0.046	0.033	0.450	11.823	3.955	18.018

Note: Total Factor Productivity (TFP) is the annual growth rate calculated as Tornqvist index. BERD is business enterprise expenditure on R&D as a percent of GDP. GERD is gross expenditure on R&D as a percent of GDP. HERD is the expenditure on R&D in higher education as a percent of GDP, and GOVERD is the government expenditure on R&D as a percent of GDP. EDU is the average education of individuals aged over 15, measured in years. CELL is the unit growth of cell phones. PC is the unit growth of personal computers. INTERNET is the growth in individual access to the Internet. RDPG is the growth in researchers, technicians, and other support staff engaged in R&D. RLG is comprised of the labor growth of those engaged in the creation of new knowledge, products, processes, methods, and systems.

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