Is the Source of Business Expenditure R&D Funding Related to International Competitiveness?

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IS THE SOURCE OF BUSINESS EXPENDITURE R&D FUNDING RELATED TO INTERNATIONAL COMPETITIVENESS

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ABSTRACT

At a time of growing fiscal instability and uncertainty about international debt levels across the OECD, this analysis provides insight into how alternative sources of private R&D investments can be leveraged more efficiently to spur international competitiveness (via Total Factor Productivity) within domestic private sectors. Using data from the OECD for 33 countries between 1990 and 2008, two fixed effects models are estimated to measure the responsiveness of alternative sources of Business Expenditure R&D (BERD) funding on long-term total factor productivity growth. For this set of countries, in both regressions of the four sources of R&D funding (Industry, Government, Abroad, Other) the only source positively correlated and significant in predicting variation in annual Total Factor Productivity growth is government investment. This holds significant implications for public policy going forward and highlights the need for data collection on the part of the OECD and other third parties that will provide insight and compare the relative effectiveness of direct and indirect government investment.
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Introduction

At a time of increasing fiscal instability and growing international debt across developed countries, public officials are facing increasing pressure to cut budgets and understand how government spending can be leveraged more efficiently to spur competitiveness within domestic private sectors.

As a prime example, U.S. debt is projected to double to $20 trillion by 2015, increasing to nearly 100 percent of Gross Domestic Product (GDP) (U.S. GPO, 2010). In May of 2010 the International Monetary Fund (IMF) issued a warning to developed countries regarding their unsustainable fiscal deficits (BBC, 2010). The IMF identified that among developed countries by 2015, current policies could lead to average debt ratios of 110 percent of GDP (BBC, 2010). For the United States while fiscal responsibility is a necessity, the manner in which economic growth has followed the previous recession has left public officials wavering between cutting budgets and jeopardizing potential economic growth. This is not however the first time that the United States has found itself in this position, facing a debt to GDP ratio of 109 percent at the culmination of World War II. By 1960 this was reduced to 46 percent of GDP through an equal combination of higher real GDP and price levels, while recording only two fiscal surpluses (Feldstein, September 23, 2010). The question is, how does the United States stimulate economic growth in the short term, in such a globally connected economic environment, in light of the severe level of fiscal debt?

"Over the last 60 years what has fueled U.S. competitiveness despite rising wages is its ability to supply a steady flow of new products. Recent reductions in taxes on business investment have been advocated on the grounds that they will increase firms’ ability to reinvest in innovative products through Research and Development, thus improving American competitiveness."
Excessive tax burdens are frequently blamed for the poor international performance of struggling American industries. Tax increases to reduce looming budget deficits are often defended on the grounds that they will reduce trade deficits.” (Summers, 1986)

Unfortunately, with the current long-term fiscal outlook, simply cutting corporate taxes is no longer a simple option. Instead, government support to companies must be focused; ensuring funds achieve the highest levels of economic growth via long-term productivity improvements.

Economic studies over the past several decades have concluded that technological innovation (and related capital and human investment) contributes nearly half of the nation’s productivity, economic growth and standard of living (Milbergs, 2010). One way to accomplish this task is to help improve both productivity and competitiveness of domestic firms through Research and Development (R&D).

Following much of the theoretical and empirical literature, cumulative R&D expenditures are used as a proxy for a stock of knowledge (Coe & Helpman, 1995). For every country in our sample a stock of industrial knowledge is utilized based on the cumulative Business Enterprise Expenditures on Research and Development (BERD), broken out by industry, government, other non-profit, and foreign. While numerous studies have shown that the estimated output elasticity is very responsive to business R&D (Nadiri, 1993), (Levy & Terleckyj, 1982), this analysis sets out to identify if unnamed incentives exist for industries to spend internally obtained funding more effectively than funding they receive from external resources. R&D spending as a whole has proven to correlate positively with annual TFP growth (Nadiri, 1993), (Yeang, January 2001) however failure to increase public R&D expenditures may result in lower private R&D investment, thus leading to lower technological progress. (Wolde-Rufael, June 2009)
Using data from the OECD for 33 countries between 1990 and 2008, a fixed effects model is estimated to measure the responsiveness of Total Factor Productivity (TFP) from different sources of Business Enterprise Expenditure R&D (BERD) funding.

**Background**

Figure 1 below reflects the average TFP growth for 33 OECD countries between 1990 and 2008, showing that average annual TFP growth has varied significantly by country over this time period. Most countries however, reported positive TFP growth.

![Figure 1: International TFP Growth 1990-2009](image_url)
Figure 2 takes this one step further, separating R&D spending by source either through tax reductions or direct government investment across 30 developed nations in 2008. Countries have the option of providing tax subsidies, direct investment, and not getting involved at all. Figure 2 shows that there is no discernable trend as to the most effective method for stimulating R&D investment. As a reference point, approximately 22 percent of U.S. government R&D spending was estimated to have come from tax incentives in 2008.

![Figure 2: Government Support through R&D Incentives (Direct vs. Indirect)](image)

To examine R&D changes over time Figure 3 identifies international BERD investment by country as a percent of GDP between 1998 and 2008. This ten year period was chosen because specific R&D investment data were not available for a number of the countries prior to 1998. The United States came in 26th place when compared by the percentage increase in BERD
spending as a percentage of GDP (OECD, 2010). Assuming R&D spending does have a direct correlation with innovation and thus projected future economic growth, this could have detrimental implications for American long-term economic competitiveness.

One indication of why this may be the case, The Economic Recovery Tax Act of 1981 adopted the first Federal R&D Tax Credit, planned to promote private investment in R&D. Since 1981, the tax credit has lapsed several times and has been temporarily renewed 14 times. Resulting from budgetary concerns; Congress has never made the tax cut permanent. When it was initially implemented the United States held the most generous R&D tax credit of any nation. Today, 16 other nations have a more generous tax break based on an index that accounts for differences in corporate tax rates among countries, as well as direct and indirect subsidies. (Villarreal, 2010)

Expressing the value of the credit as a percentage of R&D spending, the index

<table>
<thead>
<tr>
<th>Rank</th>
<th>Nation</th>
<th>BERD as a % of GDP 1998</th>
<th>BERD as a % of GDP 2008</th>
<th>% Change since 1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Portugal</td>
<td>0.15</td>
<td>0.76</td>
<td>407%</td>
</tr>
<tr>
<td>2</td>
<td>China (1998-2007)</td>
<td>0.29</td>
<td>1.04</td>
<td>259%</td>
</tr>
<tr>
<td>3</td>
<td>Turkey</td>
<td>0.12</td>
<td>0.32</td>
<td>167%</td>
</tr>
<tr>
<td>4</td>
<td>Hungary</td>
<td>0.25</td>
<td>0.53</td>
<td>112%</td>
</tr>
<tr>
<td>5</td>
<td>Iceland</td>
<td>0.73</td>
<td>1.45</td>
<td>99%</td>
</tr>
<tr>
<td>6</td>
<td>Israel</td>
<td>2.08</td>
<td>3.93</td>
<td>98%</td>
</tr>
<tr>
<td>7</td>
<td>Mexico (1998-2007)</td>
<td>0.10</td>
<td>0.18</td>
<td>80%</td>
</tr>
<tr>
<td>8</td>
<td>Singapore</td>
<td>1.11</td>
<td>1.99</td>
<td>79%</td>
</tr>
<tr>
<td>9</td>
<td>Australia (1998-2006)</td>
<td>0.67</td>
<td>1.20</td>
<td>79%</td>
</tr>
<tr>
<td>10</td>
<td>New Zealand (1999-2007)</td>
<td>0.30</td>
<td>0.51</td>
<td>70%</td>
</tr>
<tr>
<td>11</td>
<td>Austria</td>
<td>1.13</td>
<td>1.88</td>
<td>66%</td>
</tr>
<tr>
<td>12</td>
<td>Spain</td>
<td>0.46</td>
<td>0.74</td>
<td>61%</td>
</tr>
<tr>
<td>13</td>
<td>Korea</td>
<td>1.58</td>
<td>2.54</td>
<td>61%</td>
</tr>
<tr>
<td>14</td>
<td>Slovenia</td>
<td>0.70</td>
<td>1.07</td>
<td>53%</td>
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<td>1.91</td>
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</tr>
<tr>
<td>16</td>
<td>Finland</td>
<td>1.92</td>
<td>2.76</td>
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<tr>
<td>17</td>
<td>South Africa (2001-07)</td>
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<td>0.54</td>
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</tr>
<tr>
<td>18</td>
<td>Japan (1998-2007)</td>
<td>2.14</td>
<td>2.68</td>
<td>25%</td>
</tr>
<tr>
<td>19</td>
<td>Argentina (1998-2007)</td>
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<td>0.15</td>
<td>25%</td>
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<tr>
<td>20</td>
<td>Czech Republic</td>
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<td>21</td>
<td>Germany</td>
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<td>20%</td>
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<td>22</td>
<td>Switzerland (2000-08)</td>
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<tr>
<td>23</td>
<td>Italy</td>
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<td>0.60</td>
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<tr>
<td>24</td>
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<td>14%</td>
</tr>
<tr>
<td>25</td>
<td>EU27</td>
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<td>1.15</td>
<td>11%</td>
</tr>
<tr>
<td>26</td>
<td>United States</td>
<td>1.91</td>
<td>2.01</td>
<td>5%</td>
</tr>
<tr>
<td>27</td>
<td>Ireland</td>
<td>0.89</td>
<td>0.93</td>
<td>4%</td>
</tr>
<tr>
<td>28</td>
<td>Sweden (1999-2008)</td>
<td>2.68</td>
<td>2.78</td>
<td>4%</td>
</tr>
<tr>
<td>29</td>
<td>Belgium</td>
<td>1.32</td>
<td>1.32</td>
<td>0%</td>
</tr>
<tr>
<td>30</td>
<td>Russian Federation</td>
<td>0.66</td>
<td>0.65</td>
<td>-2%</td>
</tr>
<tr>
<td>31</td>
<td>United Kingdom</td>
<td>1.15</td>
<td>1.10</td>
<td>-4%</td>
</tr>
<tr>
<td>32</td>
<td>France</td>
<td>1.33</td>
<td>1.27</td>
<td>-5%</td>
</tr>
<tr>
<td>33</td>
<td>Norway (1999-2008)</td>
<td>0.92</td>
<td>0.87</td>
<td>-5%</td>
</tr>
<tr>
<td>34</td>
<td>Canada</td>
<td>1.06</td>
<td>1.00</td>
<td>-6%</td>
</tr>
<tr>
<td>35</td>
<td>Greece (1999-2007)</td>
<td>0.17</td>
<td>0.16</td>
<td>-6%</td>
</tr>
<tr>
<td>36</td>
<td>Netherlands</td>
<td>1.03</td>
<td>0.89</td>
<td>-14%</td>
</tr>
<tr>
<td>37</td>
<td>Luxembourg (2000-08)</td>
<td>1.53</td>
<td>1.32</td>
<td>-14%</td>
</tr>
<tr>
<td>38</td>
<td>Poland</td>
<td>0.28</td>
<td>0.19</td>
<td>-32%</td>
</tr>
<tr>
<td>39</td>
<td>Romania</td>
<td>0.38</td>
<td>0.18</td>
<td>-53%</td>
</tr>
<tr>
<td>40</td>
<td>Slovak Republic</td>
<td>0.51</td>
<td>0.20</td>
<td>-61%</td>
</tr>
</tbody>
</table>
shows that in 2006:

- Spain provided a 44 cent tax credit for each dollar spent on R&D.
- Mexico provided a 37 cent tax credit per dollar of R&D spending.
- Canada provided a 17 cent tax credit per dollar of R&D.
- The United States’ R&D tax credit, by contrast, resulted in only a 7 cent tax credit for each dollar spent.

Figure 4 displays annual BERD spending as a percentage of GDP for 33 OECD Countries between the years 1990 and 2008. Over time BERD spending across the OECD has continued to grow. However, while BERD spending has increased over time there has been a significant funding shift from domestic public investment to foreign sources. For the United States the data for funding from foreign sources were unavailable. As a result an alternative data point is used to compare BERD investment from foreign sources to the rest of the 32 OECD members identified in this analysis, through R&D expenditure of foreign affiliates as a percentage of R&D expenditures of enterprises over the same time period (See Figure 4).
Figures 5 and 6 display that as a result of U.S. efforts to decrease BERD government investment to levels similar to those across the OECD, the other 32 countries are catching up in terms of their relative BERD spending, as international investors and firms have taken over a previous role held by government (See Figure 3).
Resulting from significant shifts in R&D investment strategies, this analysis estimates BERD investments relevance to Total Factor Productivity (TFP), helping to identify if international competitiveness is being impacted, or if countries like the U.S. are choosing
alternative means for stimulating productivity.

**Review of the Literature:**

Historical literature on R&D has focused in length on addressing questions pertaining to why governments should have R&D tax policy and how its effectiveness should be measured. Social rates of return to R&D in industry and agriculture are far in excess of measured private rates of return which implies that private R&D investment has a much broader influence (Hall, 1993). Since those funding private R&D would prefer a concentrated impact there is likely to be an insufficient amount performed given competitive markets. The classical public finance solution to such a problem is a subsidy to the activity that generates broader impact, a subsidy designed to raise the private rate of return to the activity of the social level” (Hall, 1993).

“Competitive economies are those that have in place factors driving the productivity enhancements on which the present and future prosperity is built. An economic environment promoting competitiveness can help national economies support high incomes and ensure that the mechanisms enabling solid economic performance going into the future are in place” (Schwab, 2010). The World Economic Forum defined competition as the set of institutions, policies, and factors that determine the level of productivity of a country. “The productivity determines rates of return obtained by investment (physical, human, and technological). Because the rates of return are the fundamental drivers of the growth rates of the economy, a more competitive economy is one that is likely to grow faster in the medium to long term” (Schwab, 2010).
“The Effect of Business R&D on productivity has been investigated in many empirical studies, performed at all aggregation levels – business units, firm, industry and country levels – and for many countries (especially the United States). All of these studies reach the conclusion that R&D matters, the estimated output elasticity with respect to business R&D varying from 10 to 30 percent”; i.e. it is very responsive. (Guellec & Pottelsberghe de la Potterie, 2001).

**Does Government R&D Crowd out Private R&D?**

With numerous studies showing that R&D investment is associated with productivity growth, others have also tested the relationship between Government and Private R&D investment, specifically if any crowding out effects exist between the two.

Czarnitzki & Fier (2002) conducted an econometric analysis using German cross-sectional data at the firm level to test if there is a complementary or substitutive relationship between public funding and private R&D investment. Their approach rejected any crowding out effects between public and private investment.

Wolde-Rufael (2009) tested the co-integration and causal relationship between aggregate public R&D and private R&D funding in Taiwan for the period 1979-2007 using a co-integration\(^a\) and causality test. He found that a long-run co-integration relationship with a bi-directional causality (mutual reinforcement) between private R&D and public R&D investment. As evidence to the fact that Public and Private R&D investment are complements, public R&D innovation positively contributes to private R&D. In other words, “Failure to increase public R&D expenditure may result in lower private R&D investment where it can lead to lower technical progress”. Taiwan’s dynamic level of development over this time period is possibly an

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\(^a\)Cointegration Test- Based on the estimation of a dynamic error correction representation for the variables involved and tests whether or not the lagged levels of the variables are statistically significant by estimating unrestricted error correction (UREC) regressions considering each variable in turn as the dependent variable.
explanation of the mutual reinforcement with public and private R&D investment. However, a similar result may not take place in other developed countries, where no crowding effects are seen (Czarnitzki & Fier, 2002), but impacts to TFP may still be different depending on the source of R&D funding.

Czarnitzki & Aerts (March 2005) also tested the relationship between public R&D subsidies and private R&D activities empirically in Flanders. Their study rejected any crowding out effects, identifying that subsidized firms would have invested significantly less in R&D activities, if they had not received public R&D funding.

David, Hall & Toole (2000) surveyed a body of econometric evidence accumulated over the previous 35 years, based on time series and cross-sectional data from various levels of aggregation (laboratory, firm, industry, country (macro level). To the question of whether public and private R&D are complementary, they identified that the findings overall are ambivalent and the existing literature as a whole is subject to the criticism that the nature of the experiment(s) that the investigators envisage is not adequately specified.”

**Should governments invest in R&D?**

“Privately funded R&D investment is found to have a significant positive effect on productivity. The social marginal product of government funded research capital appears to be much lower than that of private research capital” (Lichtenberg, 1992). Put another way, the social return on investment of government funded research is comparatively lower to the same investment made by the private sector.
Nadiri (1993) published an econometric analysis to identify sources of labor productivity growth that included such inputs as labor, materials, physical capital, R&D capital and output measured by gross output. A primary issue analyzed in this paper was the calculation of the probable time period that it will take for the manufacturing sector in Korea to catch up with Japan when measured by their level of productivity. “Korean industries have reaped a significant benefit from their R&D investment, narrowing the gap between the level of labor productivity of the Korean and Japanese aggregate manufacturing sector” (Nadiri, 1993).

Nadiri (1993) also conducted an empirical analysis of the relationship between R&D and productivity. A positive and strong relationship between R&D expenditures and growth of output or total factor productivity was identified. He found that rates of return on privately financed R&D are much higher than those on publicly financed R&D and although federally financed R&D induces private sector R&D, it may not have a direct relation with a change in TFP.

At a macroeconomic level, Levy & Terleckyj (1982) examined the effects of U.S. government R&D expenditures in stimulating private R&D expenditures and in contributing to productivity growth in the private sector. They identify that $1.00 of government contract R&D performed in industry induced about $.27 of private R&D expenditure. A relationship is presented showing that spillover effects of government R&D on private sector productivity occurred and were significant; however, for the most part it did not generate private sector productivity benefits comparable to the effects of direct private investment in R&D.
David, Hall & Toole (2000) also reviewed “Seven aggregate macro econometric studies of the public/private R&D relationship”. Levy & Terleckyj (1982) analysis was identified as both the first of the macro level studies and the most definitive of its kind.

“To the extent that government policies affecting public R&D funding are correlated with initiatives intended to enhance the appropriateness of research benefits by investing firms in areas of new technological opportunity, identification of the former effects from single country analyses will remain difficult. Further utilization of international panel data seems a promising avenue for further work in this area.” (David, Hall, & Toole, 2000)

In summary, these studies share a similar theme that while government R&D investment is related to productivity growth; it generates lower private sector productivity benefits relative to those of private investment.

**Analyses looking at sources of R&D investment**

Several studies focused their analysis on comparing the relationship between alternative sources of R&D investment and long-term productivity. Coe, Helpman & Hoffmaister (2008) used pooled macroeconomic data for 21 OECD countries plus Israel over the 1971-1990 time period, estimating a country’s total factor productivity (TFP) as a function of the domestic R&D capital stock and a measure of the foreign R&D capital stock, where all the measures of R&D capital were constructed from business sectors’ R&D activities. Their findings identified that foreign R&D has beneficial effects on domestic productivity and that these are stronger the more open an economy is to trade (Coe & Helpman, 1995). This analysis was later amended and updated in 2008 applying modern panel co-integration estimation techniques to an expanded data set, and extending the analysis to include institutional variables, such as legal origin and patent
protection, in order to allow for a country’s institutional characteristics. The results of this additional amendment to the study suggest that institutional differences are important determinants of total factor productivity and they impact the degree of R&D spillovers (Coe & Helpman, 1995).

Guellec & Pottelsberghe de la Potterie (2001) estimated the association of multisource R&D spending from domestic businesses, public and foreign businesses, on multifactor productivity (MFP) growth across 16 OECD countries, using annual data between 1980 and 1998. Their analysis confirmed that for OECD countries whose firms are now at the technological frontier, keeping pace with competition implies not only building physical capacities, but increasingly to innovate. Where this analysis differs they explain that “business performed R&D may be funded by business itself or by government: it might be that business R&D has a different effect on productivity depending on its source of funding (which affects the research agenda and the incentive structure)” (Guellec & Pottelsberghe de la Potterie, 2001).

Confirming this theory, Coe & Helpman (1995) studied the extent to which a country’s productivity level depends on domestic and foreign R&D capital stocks. This analysis further attempted to test the relationship between public (total intramural business R&D expenditures), private (total public R&D capital stock, which comprises R&D expenditures performed in the higher education sector and in the government sector) and foreign R&D capital stock (weighted sum of the domestic business R&D capital stocks of the 15 other countries of the panel). Coe, Helpman & Hoffmaister (2008) revisited their analysis using dynamic OLS, confirming there is evidence of co-integration between TFP, domestic R&D capital and foreign R&D capital.
While numerous studies have identified that R&D investment is significant in predicting impacts to TFP and private R&D investment is associated with a higher elasticity of output than that of public R&D investment, what has not been addressed in sufficient detail is whether the elasticity of output from business enterprise investment varies depending on the source that it’s coming from. Furthermore, once a relationship between governments funding of BERD is identified, there has been little to no discussion regarding whether government investment has different outcomes depending on the approach of subsidization chosen.

**Research Objective**

At a time of increasing fiscal instability and growing international debt, the aim of this analysis is to provide policy perspectives on how public officials can address growing concerns about the competitiveness of their industries, and the most efficient means through which to invest in their private sectors. Based on similar analysis (Nadiri, 1993), government investment in BERD is projected to exert a significant influence on TFP growth but less so than private investment. This analysis will extend numerous econometric studies by Gullec & Pottelsberghe de la Potterie (2001) and Coe, Helpman & Hoffmaister (2008) to test if the source of BERD spending (Industry, Government, Foreign and Other) is important to annual TFP growth.

It is hypothesized that TFP is positively correlated with R&D spending. Since all of the funding is being spent by businesses it was hypothesized that all four sources would be positively related to TFP growth. This relationship is projected to be strongest with industry funded BERD especially when compared to government investment. With foreign BERD
overtaking public BERD across the developed and developing world (See Figure 4) foreign investment is also projected to have a strong relationship with TFP growth.

**Data**

Annual BERD source spending data were attained from the OECD Main Science and Technology Database. For every country BERD percentage spending by source was estimated against a measure of annual growth in Total Factor Productivity (TFP), defined as the change in output per unit of combined inputs.

Annual Total Factor Productivity Growth data were pulled from The Conference Board Total Economy Database for the years 1990 through 2008. International BERD data were pulled from the OECD Main Science and Technologies database for 33 OECD countries for the years 1990 and 2008. BERD data used from this database included total BERD expenditures by nation, BERD as a percent of GDP, percentage of BERD financed by industry, government, other National sources, and foreign source.

Building off of other works and analyses of productivity growth and investment spending, to account for other possible determinants of TFP annual data were pulled from other sections of the OECD and the World Bank datasets (World Development Indicators and Global Development Finance, 2010). Based on previous analyses data were included on total long-term interest rates (Becker & Pain, 2003), level of national debt as a percentage of GDP (Mitchell & Debnam, 2010), total level of annual trade (imports + exports) as a percentage GDP (Skipton, 2007), and unemployment as a portion of the total population (Vallanti, 2003). Lastly to test
whether previous GDP growth is associated with current and future productivity, data were pulled on annual GDP growth to control for any historical differences between poor and rich countries.

**Model Specification**

Leveraging a methodology from a recent analysis of TFP growth determinants (Danquah, Moral-Benito, & Ouattara, 2011), a fixed effects model is used to estimate the contribution of BERD investment on annual TFP growth. This analysis distinguishes between the responsiveness of various sources of BERD investment: industry, government, foreign, and other domestic sources (universities, etc) to TFP growth. In doing so, dummy variables are used to control for time and country because they are not assumed to be constant. Confirming this Danquah, Moral Benito & Ouattara (2011) promoted the need for country and year specific effects since they explain a large portion of TFP variation.

In a previous analysis Levy & Teleckyj (1982) identified that time lags exist between R&D expenditures and productivity growth. Helping to visualize why this also appears to be true for this analysis, Figure 8 shows no discernable relationship between BERD spending as a percentage of GDP and TFP growth when no lags are accounted for. This is likely because benefits of R&D investment are unrealized by industries immediately as this funding will need some time for implementation and spending prior to showing any discernable relationship with productivity.
Lags were used to account for a delay in the impact that R&D funding has on TFP growth after an initial investment is made. A longer lag is assumed for government BERD funding consistent with the view that public funding will take longer to impact TFP growth, a result of the lengthy transfer process that is required of government contracting as well as specific restrictions and oversight on how this funding is spent by businesses. Lags representing long-term relationships have been set at one year for business, foreign, and other sources of BERD funding, and two years for public funding. These lags were determined by following the same procedure by Gullec & Pottelsberge de la Potterie (2001), whereby alternative lags were tested and those delivering the most significant results were chosen.

A fixed effects model controlling for years and country is represented below. Country dummy is split into two categories controlling for rich (GDP per capita > $20K) and poor (GDP per capita ≤ $20K).
per capita < $20K) countries (See Appendix B). All independent variables (except for the two
dummy variables YEAR and CONTRY) are measured in log form because of the equivalency of
this measure to elasticity. After conducting all of the necessary diagnostics on equation 1 below,
some minor model specification concerns were identified (See Appendix B). In order to correct
for some of these concerns two models (equations 1 and 2 below) were estimated to measure the
responsiveness of alternative sources of BERD spending on a non-logged form of TFP growth
(equation 1) and a logged form TFP growth (equation 2).

**Equation 1:**\[ TFP = B0 + \log B1(INDUSTRY)_{ct-1} + \log B2(ABROAD)_{ct-1} + \log B3 \\
(OTHER)_{ct-1} + \log B4(GOVERNMENT)_{ct-2} + \log B5(BERDOFGDP)_{ct} + \log B6 \\
(INTEREST\_RATE)_{ct} + \log B7(TRADE)_{ct} + \log B8(GDPgrowth)_{ct} + \log B9(DEBT)_{ct} + \\
B10(YEAR)_{ct} \log B11(UNEMPL\_POP)_{ct} + B12(COUNTRY)_{ct} \]

**Equation 2:**\[ \log(TFP) = B0 + \log B1(INDUSTRY)_{ct-1} + \log B2(ABROAD)_{ct-1} + \log B3 \\
(OTHER)_{ct-1} + \log B4(GOVERNMENT)_{ct-2} + \log B5(BERDOFGDP)_{ct} + \log B6 \\
(INTEREST\_RATE)_{ct} + \log B7(TRADE)_{ct} + \log B8(GDPgrowth)_{ct} + \log B9(DEBT)_{ct} + \\
B10(YEAR)_{ct} \log B11(UNEMPL\_POP)_{ct} + B12(COUNTRY)_{ct} \]

The variables for (country c and time t) are defined as follows:
Table 1: Variable Descriptions

Leveraging previous analyses on this subject matter, table 2 below provides a preliminary hypotheses of the directional relationship between the dependent and independent variables.
Table 2: Preliminary Hypothesis of Directional Relationship between the Dependent and Independent variables\textsuperscript{b, c}

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Variable</th>
<th>Value</th>
<th>Hypothesis</th>
<th>Source</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent</td>
<td>Industry Expenditure on R&amp;D</td>
<td>%</td>
<td>+</td>
<td>Effects of Government R&amp;D on Private R&amp;D Investment and Productivity (Ley, Terlecky)</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>Abroad Expenditure on R&amp;D</td>
<td>%</td>
<td>+</td>
<td>Effects of Government R&amp;D on Private R&amp;D Investment and Productivity (Ley, Terlecky)</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>Other Expenditure on R&amp;D</td>
<td>%</td>
<td>+</td>
<td>Effects of Government R&amp;D on Private R&amp;D Investment and Productivity (Ley, Terlecky)</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>Government Expenditure on R&amp;D</td>
<td>%</td>
<td>+</td>
<td>Effects of Government R&amp;D on Private R&amp;D Investment and Productivity (Ley, Terlecky)</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>BERD as % of GDP</td>
<td>%</td>
<td>+</td>
<td>R&amp;D spending in the high-tech sector and economic growth (FALK)</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>Long-Term Interest Rates</td>
<td>%</td>
<td>-</td>
<td>What Determines Industrial R&amp;D Expenditure in the UK? (Becker, Pain)</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>Total Trade as a % of GDP</td>
<td>%</td>
<td>+</td>
<td>Trade Openness, Investment, and Long-Run Economic Growth (Skipton)</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>Annual GDP Growth</td>
<td>%</td>
<td>+</td>
<td>Total Factor Productivity Growth: Survey Report, Asian Productivity Organization</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>debt as a % of GDP</td>
<td>%</td>
<td>-</td>
<td>In the Long Run, We’re All Crowded Out (Mitchell, Debnam)</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>Unemployment as a percentage of total population</td>
<td>%</td>
<td>+</td>
<td>Productivity Growth and Employment: Theory and Panel Estimates (Vallanti)</td>
<td></td>
</tr>
</tbody>
</table>

Estimation Results

Estimates were derived from a fixed effects model (controlling for country and years).

The primary variables controlling for change in TFP were four sources of BERD funding:

\textsuperscript{b} Total Factor Productivity (TFP) growth - Reflects the annual change in total output of a nation divided by the combined set of inputs (labor, capital, etc). This variable reflects the joint effects of many factors including new technologies, economies of scale, managerial skill, and changes in the organization of production that are inherently correlated with Business Enterprise Expenditures on Research and Development.

\textsuperscript{c} Long Term Interest Rate - Long term (in most cases 10 years) government bonds are the instrument whose yield is used as the representative ‘interest rate’ for this area. Generally the yield is calculated at the pre-tax level and before deductions for brokerage costs and commissions and is derived from the relationship between the present market value of the bond and that at maturity, taking into account also interest payments paid through to maturity. (OECD, 2010) This variable is used as a representation of the availability of funding. For firms looking to invest in R&D the availability of funding is a significant factor in private investment decisions and could impact foremost the amount of money that is both invested and raised from external sources as well as companies long term productivity.
Industry, Abroad, Other and Government. Relevant control variables were incorporated into the regressions including unemployment, debt as a percentage of GDP, annual GDP growth, total trade (imports + exports) as a percentage of GDP, long-term interest rates, and total BERD spending as a percentage of GDP\(^d\). (See Appendix B for complete regression results)

In attempting to resolve any model specification errors the dependent variable TFP was logged in regression 2. Unfortunately across the spectrum of OECD countries TFP growth over the last 20 years has not always been positive. Since negative numbers cannot be logged, several observations were lost. The initial regression had weak predictive power. Logging the dependent variable TFP growth truncated the data significantly resulting in a loss of 230 negative observations. A solution to this was found in Lingxin Hao’s (2004) work, which analyzed the impact of immigration on the distribution of U.S. wealth. To include zero and negative values of TFP growth, using this method, logs for TFP were transformed (renamed as tfp2) as follows:

- If TFP growth is positive, the log of TFP is simply the log of the value
- If TFP growth is zero, the log of TFP is set equal to zero
- If TFP growth is negative, the absolute value of TFP is logged and assigned a negative sign (Hao, 2004)

After regressing the full list of independent variables on tfp2, the predictive value of the model R-squared decreased from .38 to approximately .20. However, model specification

\(^d\) In removing each of the control variables and examining diagnostics and regression results, significant sensitivities were identified based on model specification. Sensitivities were likely a result of the limited number of observations that were used to conduct this analysis. After conducting all of the necessary diagnostics including the Breusch-Pagen/ Cook-Weisberg test for heteroskedasticity, Ramsey reset test checking for omitted variable bias, the linktest checking for model specification, plotting the dependent variables’ residuals against its fitted values, plotting the dependent variables against its residuals, regression 1 appeared to have the model of best fit for this analysis. However, there was still a model specification issue. (See Appendix B)
improved significantly while the diagnostics remained reflective of a robust model. (See Appendix B)

Table 4 below presents the results of the two models for the dependent variables TFP and tfp2 respectively.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Regression 1</th>
<th>Regression 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Variable</td>
<td>TFP</td>
<td>tfp 2</td>
</tr>
<tr>
<td>Industry as a source of Business Expenditure R&amp;D</td>
<td>-0.874 (-33)</td>
<td>2.326 (1.03)</td>
</tr>
<tr>
<td>Abroad as a source of Business Expenditure R&amp;D</td>
<td>-0.415 (-1.85)*</td>
<td>0.059 (.31)</td>
</tr>
<tr>
<td>Other as a source of Business Expenditure R&amp;D</td>
<td>-1.165 (-1.43)</td>
<td>0.042 (.43)</td>
</tr>
<tr>
<td>Government as a source of Business Expenditure R&amp;D</td>
<td>1.081 (2.92)**</td>
<td>0.645 (2.07)**</td>
</tr>
<tr>
<td>BERD as a % of GDP</td>
<td>0.041 (.14)</td>
<td>-0.297 (-1.20)</td>
</tr>
<tr>
<td>Long Term Interest Rates</td>
<td>-2.587 (-4.15)**</td>
<td>-0.766 (-1.46)</td>
</tr>
<tr>
<td>Total Trade as a % of GDP</td>
<td>0.452 (2.84)**</td>
<td>0.044 (.33)</td>
</tr>
<tr>
<td>Annual GDP growth</td>
<td>1.42 (5.32)**</td>
<td>0.467 (2.08)**</td>
</tr>
<tr>
<td>debt as a % of GDP</td>
<td>-0.582 (-2.52)**</td>
<td>0.155 (.80)</td>
</tr>
<tr>
<td>Unemployment as a % of the Population</td>
<td>0.839 (2.16)**</td>
<td>0.049 (.15)</td>
</tr>
<tr>
<td>yr dummy</td>
<td>0.011 (-.24)</td>
<td>0.042 (1.13)</td>
</tr>
<tr>
<td>Poor Country Dummy</td>
<td>-1.487 (-3.25)**</td>
<td>0.112 (.29)</td>
</tr>
<tr>
<td>Constant</td>
<td>28.314 (.31)</td>
<td>-96.297 (-1.26)</td>
</tr>
<tr>
<td>R^2</td>
<td>.387</td>
<td>0.197</td>
</tr>
<tr>
<td>F-Score</td>
<td>5.48</td>
<td>2.13</td>
</tr>
<tr>
<td>Observations</td>
<td>117</td>
<td>117</td>
</tr>
</tbody>
</table>

* = P < .1  
** = P < .05  
*** = P < .01

Table 3: Regression Table

The hypothesis was not confirmed: total BERD spending when measured as a percentage of GDP was statistically insignificant with tfp2 and TFP. This is in contrast to Coe & Helpman (1995) and other authors who found a positive and significant relationship between R&D
investment and TFP growth. Even more so, they showed that private investment on R&D had a higher elasticity than public investment. Although the hypothesized variables did not perform as expected, most of the control variables were statistically significant.

Furthermore, confirming that failure to increase public R&D expenditures may result in lower private R&D investment, thus leading to lower technological progress” (Wolde-Rufael, June 2009) both regressions identified a positive and significant correlation between government funding of business R&D investment and annual TFP growth.

Regression 1:

- **Government, Industry and Other sources of BERD funding** – Public BERD spending were significant and positively correlated with annual TFP growth at the 99 percent confidence interval. However, neither business nor other sources of BERD were significant with TFP growth. Results of this analysis are contrary to a similar analysis by Coe & Helpman (1995) which identified that private R&D expenditures were most significant and had a stronger relationship with TFP growth when compared to public investment.

**Foreign BERD spending** was also surprisingly negatively correlated with TFP growth at the 90 percent confidence interval. Contrary to this papers original hypothesis, this may hold significant implications for countries like the United States who have shown a sign of decreasing BERD government investment to levels similar to those across the OECD, as international investors and firms have taken over a previous role held by government (See Figure 4).
It was also contrary to the hypothesis that resulting from a shift to global trade flows and a very integrated global economy, foreign BERD funding would also be significant in impacting long term TFP growth. Since all funding is eventually being spent by businesses it was hypothesized that all four sources would be significant and positively correlated with TFP growth but with different variations in elasticity or responsiveness. On the contrary, the level of government investment seemed more associated with TFP growth than the other three sources of BERD funding. This may reflect that industry and foreign sources of BERD funding are already the primary sources of industry expenditures and do not vary significantly as a percentage of total BERD funding across nations. However, public investment both as a percentage of total BERD spending as well as the instrument used (direct and indirect public investment) across the 33 OECD nations accounted does waver significantly (See Figure 2). Thus, while BERD expenditures as a whole may have a higher elasticity on TFP growth than government investment as demonstrated by Coe & Helpman (1995), the source of BERD expenditures most related to variability in TFP growth was government investment.

- **Long-term interest rates** – Changes in interest rates were negatively correlated with annual TFP growth. This follows general theory that companies and even governments will be induced to invest more funding in R&D when they have access to relatively cheaper capital.
• **Trade Levels** – Changes in total trade (imports + exports) as a percentage of each country’s GDP, was positively correlated with annual TFP growth at the 95 percent confidence interval.

• **Annual GDP growth** - Confirming that TFP growth is highly dependent on each countries prior economic performance, historical changes in GDP growth were positively related to TFP growth.

• **Debt as a percentage of GDP** – Changes in the level of debt that each country holds as a percentage of GDP, was negatively correlated with annual TFP growth.

• **Unemployment** – Changes in the level of unemployment as a percentage of the total population was positively correlated with annual TFP growth. As unemployment increases, for companies to continue competing in the global economy they are forced to increase their productivity.

**Regression 2**

• **Sources of BERD funding** – Similar to regression 1 of the sources of BERD funding only public funding showed significance in its relation to annual TFP growth (95 percent confidence interval).

• **Annual GDP growth** – Also similar to regression 1 changes in historical GDP growth was statistically significant and thus related to long term productivity growth.

• **Long-term interest rates** – Contrary to my original hypothesis and regression 1, changes in long–term interest rates were statistically insignificant in predicting changes in long-term annual TFP growth. By the same principle common theory would have assumed that
long term interest rates measuring the cost of borrowing, would impact private
investment and thus long-term TFP growth by private industries.

- **National Debt** – Contrary to my original hypothesis and the results of regression 1, National debt as a percentage of the total population was statistically insignificant as a determinant of annual TFP growth. Confirming this result, Czarnitzki & Fier’s analysis rejected any crowding out effects between public and private investment.

**Limitations of the Analysis**

**Size of the Dataset:** Although this analysis was conducted on 33 OECD countries between 1990 and 2009, the regressions were based on anywhere between 117 and 170 observations depending on the combination of control variables used because of missing data points. As a result, significant sensitivity to model specification changes was identified and may speak to the validity of these results.

**Regression Technique:** The findings for two models were provided in the previous section because both show some limitations in their results. Regression 2 shows convincing diagnostics but a much lower $R^2$ value than other model specifications, and some questionable results regarding the lack of statistical significance for a number of key variables. Regression 1 confirms many of the assumptions seen in other academic papers. Control variables other than the four sources of BERD funding, had a much higher predictive value but showed some model specification concerns. It would be interesting to test if an alternative regression technique is more predictive at identifying appropriate variability in either TFP or $tfp2$. Alternative analyses
have used other techniques including but not limited to auto-regression analysis and co-integration and causality tests, but were beyond the scope of this analysis.

**Collect data on Direct vs. Indirect Investment:** In a world where multinational enterprises are increasingly globalizing their R&D activities, governments have to compete in attracting the R&D activities of these corporations. Incentives such as R&D tax subsidies are a differentiator that can make a country relatively more attractive than its competitors (OECD, 2010). While government investment was the only source of funding positively related with TFP growth, this included both direct (grants) or indirect (tax subsidies). Unfortunately, direct and indirect public R&D expenditure data was not part of OECD’s Main Science and Technology Database, but has been included in some recent reports on an experimental basis based on an ad-hoc request to international contacts. Given that the availability of primary sources needed to produce such estimates varies widely, they are far from being harmonized. The OECD had conducted a similar pilot in the past, the results of which were published in the 2008 STI Outlook report, but there are no similar times series available, and it is still unclear whether they will continue this data collection in the future.

**Suggestions for Future Analysis**

Throughout this paper, it is referenced that governments can offer direct support via grants, favorable loans or procurement or they can use indirect fiscal incentives, such as R&D tax incentives (OECD, 2010). What isn’t addressed is that differences may exist in the elasticity
of productivity from government BERD investment when comparing government direct versus indirect subsidization of BERD spending.

Historical direct and indirect trend data on international government BERD spending were obtained from the Internal Revenue Service (IRS) special tabulations historical database via tax credit claims and direct government spending. Displayed in figure 7, as total U.S. government BERD spending decreased significantly between 1990 and 2006 (No data were available past 2006), the allocation of funding is shifting towards indirect investment (tax credits) versus direct government investment.

![Image of graph showing percentage of BERD financed by government and through a tax credit.](image)

**Figure 7: Historical percent of BERD spending from Government and through a tax credit**

An indication of this trend is seen through the proposed 2011 Federal Budget, proposing to invest in “Innovation to create industries and Jobs of Tomorrow” through both direct and indirect government spending (R&D tax credit). (OMB) This plan:

- Invests $61.6 billion in civilian research and development
- Invests of $4 billion in a National Infrastructure Innovation and Finance Fund to
invest in projects of regional or national significance.

- Infuses R&D funding to support renewable energy and energy efficiency technologies such as advanced batteries, solid-state lighting, solar, biomass, geothermal, and wind power.

Compared to direct subsidies, R&D tax credits allow market forces to determine which R&D projects are carried out and ultimately subsidized, according to each country’s eligibility rules. However, the downside is a more limited capacity by Government to ensure that the subsidy results in additional levels of R&D with high social spillovers (OECD, 2010).

If Government investment is most important, it would be beneficial to compare the effectiveness of both types of government R&D investments, helping to illuminate public officials on how best to allocate their limited funding most effectively.

**Policy Implications for the United States**

Currently, the United States is struggling to reemerge from a global financial recession with a nine percent unemployment rate that will likely stymie any significant economic growth over the short term. With neither monetary policy, nor private investment having much impact, government direct investment has been the only short-term solution to stimulating long-term economic stability. From another perspective, with countries like Greece, Spain, Ireland, and most recently Portugal receiving downgrades on their debt and thus facing significant market risks of default, U.S. politicians must address a growing fiscal debt that is projected to reach as much as 100% of GDP in the not so distant future. Even if investors begin to fear the possibility
of a U.S. default, the global economic and social implications are both immeasurable and possibly catastrophic.

Going forward public leadership will be forced to evaluate future government spending on a criteria heavily weighed upon measuring opportunity costs and the marginal utility of each additional dollar spent versus the implications that government default may have on long-term stability. In the interest of addressing the marginal utility of dollars spent and the opportunity cost of specific government funding, this analysis set out to identify the most effective funding sources for achieving TFP growth. Although the results of both regressions 1 and 2 may benefit from sensitivity analysis through the use of alternative modeling methodologies, the relationship between Government financing of R&D activities and TFP growth should not be discounted in fiscal evaluations completely.

As mentioned earlier, the United States faced a similar level of debt right after World War II and climbed out of it with an equal combination of higher real GDP and a higher price level, while recording only two fiscal surpluses. Budget deficits of this magnitude cannot be controlled without long-term economic growth on the part of the US private sector. Adding to a robust collection of analyses, this paper identifies the value that public investment in R&D related activities could have on long-term TFP, and as a result long-term economic growth that could help to shed the weight of international debt with the least hardship to future American generations.
Appendix A: Regression Diagnostics

Table 3 below provides the correlation statistics for the independent variables in regressions 1 and 2.

<table>
<thead>
<tr>
<th></th>
<th>L1.logIND</th>
<th>L1.logabroad</th>
<th>L1.logother</th>
<th>L2.logGov</th>
<th>logBERDGDP</th>
<th>loginterest</th>
<th>logtrade</th>
<th>logGDPgrowth</th>
<th>logdebtl</th>
<th>yrdummy</th>
<th>logunempl</th>
<th>poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1.logIND</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1.logabroad</td>
<td>-0.8191</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>L1.logother</td>
<td>0.3821</td>
<td>-0.2791</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2.logGov</td>
<td>-0.6449</td>
<td>0.5297</td>
<td>-0.0673</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>logBERDGDP</td>
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<td>-0.4176</td>
<td>-0.2886</td>
<td>-0.5057</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>loginterest</td>
<td>-0.2394</td>
<td>0.3019</td>
<td>0.1203</td>
<td>0.4597</td>
<td>-0.3269</td>
<td>1</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>logtrade</td>
<td>-0.1492</td>
<td>0.2727</td>
<td>-0.1337</td>
<td>0.2941</td>
<td>0.0089</td>
<td>0.346</td>
<td>1</td>
<td></td>
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</tr>
<tr>
<td>logGDPgrowth</td>
<td>0.1189</td>
<td>-0.136</td>
<td>0.0409</td>
<td>-0.0602</td>
<td>-0.0682</td>
<td>0.2385</td>
<td>0.1253</td>
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<tr>
<td>logdebtl</td>
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<td>0.1395</td>
<td>-0.2485</td>
<td>-0.0774</td>
<td>0.1308</td>
<td>-0.5018</td>
<td>0.0294</td>
<td>-0.3386</td>
<td>1</td>
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<tr>
<td>yrdummy</td>
<td>-0.0336</td>
<td>-0.0506</td>
<td>-0.174</td>
<td>-0.0011</td>
<td>0.2357</td>
<td>-0.2837</td>
<td>0.1228</td>
<td>-0.1218</td>
<td>-0.1407</td>
<td>1</td>
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<td></td>
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<td>logunempl</td>
<td>0.0565</td>
<td>0.1595</td>
<td>0.2247</td>
<td>0.2683</td>
<td>-0.2067</td>
<td>0.068</td>
<td>-0.0218</td>
<td>-0.0869</td>
<td>0.1296</td>
<td>-0.2431</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>poor</td>
<td>0.095</td>
<td>-0.3117</td>
<td>0.2999</td>
<td>0.3273</td>
<td>-0.2158</td>
<td>0.1277</td>
<td>0.1957</td>
<td>0.3601</td>
<td>-0.2764</td>
<td>0.1837</td>
<td>0.0463</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4: Correlation matrix of independent variables in Fixed Effects analysis

Regression 1: Diagnostics
Plotting the dependent variables’ residuals against its fitted values and conducting the Breusch-Pagen/ Cook-Weisberg test, showed no signs of heteroskedasticity.
The Ramsey Reset test verified that the control variables included within regression 1 were sufficient to ensure that there was no omitted variable bias within this regression.

<table>
<thead>
<tr>
<th>Ramsey RESET test using powers of the fitted values of TFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ho: model has no omitted variables</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$F(3, 101)$ = 1.34</td>
</tr>
<tr>
<td>$\text{Prob} &gt; F$ = 0.2658</td>
</tr>
</tbody>
</table>

Conducting the linktest and plotting the dependent variable against its residuals uncovered some minor model specification concerns.
Regression 1 Linktest

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>Number of obs</th>
<th>=</th>
<th>117</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>96.29581</td>
<td>2</td>
<td>48.14791</td>
<td>Prob &gt; F</td>
<td>=</td>
<td>0</td>
</tr>
<tr>
<td>Residual</td>
<td>142.8148</td>
<td>114</td>
<td>1.252761</td>
<td>R-squared</td>
<td>=</td>
<td>0.4027</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Adj R-squared</td>
<td>=</td>
<td>0.3922</td>
</tr>
<tr>
<td>Total</td>
<td>239.1106</td>
<td>116</td>
<td>2.061298</td>
<td>Root MSE</td>
<td>=</td>
<td>1.1193</td>
</tr>
</tbody>
</table>

| TFP     | Coef.   | Std. Err. | t     | P>|t| | [95% Conf. Interval] |
|---------|---------|-----------|-------|------|----------------------|
| _hat    | 0.834641| 0.151056  | 5.53  | 0    | 0.5354006 1.133881   |
| _hatsq  | 0.146143| 0.085185  | 1.72  | 0.089| -0.0226089 0.314894  |
| _cons   | -0.07244| 0.121515  | -0.6  | 0.552| -0.313158 0.168281   |

To rectify possible model specification error, the dependent variable TFP was logged in regression 2.

**Regression 2:**
Plotting the dependent variables’ residuals against its fitted values and conducting the Breusch-Pagen/ Cook-Weisberg test, regression 2 still showed no signs of heteroskedasticity.
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

<table>
<thead>
<tr>
<th>Ho: Constant variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables: fitted values of tfp2</td>
</tr>
<tr>
<td>chi2(1) = 0.08</td>
</tr>
<tr>
<td>Prob &gt; chi2 = 0.7808</td>
</tr>
</tbody>
</table>

The Ramsey Reset test confirmed that logging the dependent variables did not result in any omitted variable bias.

Ramsey RESET test using powers of the fitted values of tfp2

<table>
<thead>
<tr>
<th>Ho: Model has no omitted variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>F(3, 101) = 1.45</td>
</tr>
<tr>
<td>Prob &gt; F = 0.2325</td>
</tr>
</tbody>
</table>

Plotting the dependent variable against its residuals and the conducting a link test confirmed that logging the dependent variable TFP erased the model specification concerns from regression 1. In doing so however, the predictability of this model on TFP was reduced significantly.
<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>Number of obs</th>
<th>=</th>
<th>117</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>25.46505</td>
<td>2</td>
<td>12.73253</td>
<td>Prob &gt; F</td>
<td>=</td>
<td>0</td>
</tr>
<tr>
<td>Residual</td>
<td>103.5392</td>
<td>114</td>
<td>0.908238</td>
<td>R-squared</td>
<td>=</td>
<td>0.1974</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Adj R-squared</td>
<td>=</td>
<td>0.1833</td>
</tr>
<tr>
<td>Total</td>
<td>129.0042</td>
<td>116</td>
<td>1.112105</td>
<td>Root MSE</td>
<td>=</td>
<td>0.95302</td>
</tr>
</tbody>
</table>

| tfp2       | Coef.   | Std. Err. | t     | P>|t| | [95% Conf. Interval] |
|------------|---------|-----------|-------|-----|---------------------|
| _hat       | 0.975053| 0.264236  | 3.69  | 0   | 0.4516033 - 1.498503 |
| _hatsq     | 0.045879| 0.33976   | 0.14  | 0.893 | 0.6271831 - 0.718941 |
| _cons      | -0.00781| 0.107373  | -0.07 | 0.942 | 0.2205134 - 0.204896 |
## Appendix B: Country Classification by GDP/Capita

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Country Code</th>
<th>Average GDP Per Capita 2010 US $s</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Luxembourg</td>
<td>LUX</td>
<td>$58,366.66</td>
<td>Rich</td>
</tr>
<tr>
<td>2</td>
<td>Norway</td>
<td>NOR</td>
<td>$45,898.64</td>
<td>Rich</td>
</tr>
<tr>
<td>3</td>
<td>Switzerland</td>
<td>CHE</td>
<td>$38,877.77</td>
<td>Rich</td>
</tr>
<tr>
<td>4</td>
<td>Denmark</td>
<td>DNK</td>
<td>$35,243.56</td>
<td>Rich</td>
</tr>
<tr>
<td>5</td>
<td>Iceland</td>
<td>ISL</td>
<td>$35,025.21</td>
<td>Rich</td>
</tr>
<tr>
<td>6</td>
<td>United States</td>
<td>USA</td>
<td>$29,601.81</td>
<td>Rich</td>
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<tr>
<td>7</td>
<td>Ireland</td>
<td>IRL</td>
<td>$33,103.76</td>
<td>Rich</td>
</tr>
<tr>
<td>8</td>
<td>Sweden</td>
<td>SWE</td>
<td>$31,013.10</td>
<td>Rich</td>
</tr>
<tr>
<td>9</td>
<td>Japan</td>
<td>JPN</td>
<td>$32,696.52</td>
<td>Rich</td>
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<tr>
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<td>NLD</td>
<td>$27,889.76</td>
<td>Rich</td>
</tr>
<tr>
<td>11</td>
<td>Finland</td>
<td>FIN</td>
<td>$28,951.38</td>
<td>Rich</td>
</tr>
<tr>
<td>12</td>
<td>Austria</td>
<td>AUT</td>
<td>$27,908.14</td>
<td>Rich</td>
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<tr>
<td>13</td>
<td>United Kingdom</td>
<td>GBR</td>
<td>$26,351.58</td>
<td>Rich</td>
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<tr>
<td>14</td>
<td>Belgium</td>
<td>BEL</td>
<td>$26,742.76</td>
<td>Rich</td>
</tr>
<tr>
<td>15</td>
<td>Germany</td>
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<td>16</td>
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<td>FRA</td>
<td>$27,574.59</td>
<td>Rich</td>
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<tr>
<td>17</td>
<td>Canada</td>
<td>CAN</td>
<td>$23,766.80</td>
<td>Rich</td>
</tr>
<tr>
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<td>Australia</td>
<td>AUS</td>
<td>$24,395.55</td>
<td>Rich</td>
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<tr>
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<td>Italy</td>
<td>ITA</td>
<td>$22,637.57</td>
<td>Rich</td>
</tr>
<tr>
<td>20</td>
<td>Spain</td>
<td>ESP</td>
<td>$18,439.34</td>
<td>Poor</td>
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<tr>
<td>21</td>
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<td>NZL</td>
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<tr>
<td>22</td>
<td>Israel</td>
<td>ISR</td>
<td>$17,088.49</td>
<td>Poor</td>
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<tr>
<td>23</td>
<td>Greece</td>
<td>GRC</td>
<td>$15,522.44</td>
<td>Poor</td>
</tr>
<tr>
<td>24</td>
<td>Portugal</td>
<td>PRT</td>
<td>$13,400.70</td>
<td>Poor</td>
</tr>
<tr>
<td>25</td>
<td>Slovenia</td>
<td>SVN</td>
<td>$13,051.27</td>
<td>Poor</td>
</tr>
<tr>
<td>26</td>
<td>Korea, Rep.</td>
<td>KOR</td>
<td>$12,072.97</td>
<td>Poor</td>
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<tr>
<td>27</td>
<td>Czech Republic</td>
<td>CZE</td>
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<tr>
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<td>Slovak Republic</td>
<td>SVK</td>
<td>$7,827.62</td>
<td>Poor</td>
</tr>
<tr>
<td>29</td>
<td>Hungary</td>
<td>HUN</td>
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<td>Poor</td>
</tr>
<tr>
<td>30</td>
<td>Mexico</td>
<td>MEX</td>
<td>$6,000.64</td>
<td>Poor</td>
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<tr>
<td>31</td>
<td>Poland</td>
<td>POL</td>
<td>$5,422.11</td>
<td>Poor</td>
</tr>
<tr>
<td>32</td>
<td>Chile</td>
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<tr>
<td>33</td>
<td>Turkey</td>
<td>TUR</td>
<td>$4,571.32</td>
<td>Poor</td>
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</tbody>
</table>
References


Wolde-Rufael, Y. (June 2009). Does Public R&D Crowd Out Private R&D? A Note from Taiwan, ROC. *Journal of Economic Development Volume 34, Number 1*.

