

## An Approach to Estimate Depreciation Rate for Constructing R&D Capital Stock

### Ar-Ge Sermaye Stoğu Oluşturmak İçin Amortisman Oranı Tahmininde Bir Yaklaşım

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#### Abstract

Measuring social returns to Research and Development expenditures (R&D) requires construction of R&D capital stock because there are no data on R&D capital stocks in the official accounts. However, the problem with the calculating the R&D stock capital from R&D expenditures is problematic because one has to make an assumption about the unknown depreciation rate of R&D capital. Generally, empirical studies construct to R&D capital stock using the perpetual inventory method with the assumption of depreciation rate ranges from 5% to 15%. The assumption implies that, independently of whether R&D is carried out or not, every year a constant percentage of the R&D capital stock become obsolete. Most economists would agree that knowledge produced via R&D facilities does not depreciate in such a mechanical way. In this study we propose to construct R&D capital stock and estimate returns to R&D simultaneously with grid search methodology that given depreciation rate ranges from -20% to 20%. Used production function approach to estimate depreciation rate and Seemingly Unrelated Regression estimator is applied to panel data from 13 OECD countries for the period 1985-2005. Results show that estimated depreciation rate is -3% implying appreciation of R&D stock rather than depreciation.

**Keywords:** Business Sector R&D Stock, Depreciation Rate Estimation, Multifactor Productivity, Seemingly Unrelated Regression, Production Function Approach

#### Öz

Araştırma ve Geliştirme (Ar-Ge) sermaye stoklarıyla ilgili resmi hesaplarda hiçbir veri olmaması sebebiyle, Ar-Ge harcamalarının sosyal getirilerini ölçmek Ar-Ge sermaye stokunun oluşturulmasını gerektirir. Ancak, Ar-Ge sermaye stoğunun Ar-Ge harcamalarından hesaplanması problemlidir, çünkü Ar-Ge sermayesinin bilinmeyen amortisman oranı ile ilgili bir varsayım yapılması zorunludur. Genellikle, ampirik çalışmalar %5 ile %15 arasında değişen amortisman oranı varsayımı ile devamlı envanter yöntemi kullanılarak Ar-Ge sermaye stoğunu hesaplanmaktadır. Varsayım ima ettiği, Ar-Ge faaliyetlerinin gerçekleştirilip ya da gerçekleştirilmediğinden bağımsız, her yıl Ar-Ge sermaye stokunun sabit bir yüzdesi kullanılmaz hale gelecektir. Birçok ekonomist Ar-Ge faaliyetleri sonucunda üretilen bilginin mekanik bir şekilde değer yitirmediğini kabul eder. Bu çalışma, grid arama yöntemi kullanılarak, amortisman oranını -%20 ve %20 aralığında değiştirilerek, Ar-Ge sermaye stoğunu ve Ar-Ge getirilerinin tahminini eş zamanlı hesaplamayı amaçlar. Amortisman oranını tahmin etmek için üretim fonksiyonu yaklaşımı kullanıldı ve Görünürde İlişkisiz Regresyon tahmin edicisi 13 OECD ülkesinin panel verilerine 1985-2005 dönemi için uygulandı. Sonuçlar tahmini edilen amortisman oranı % -3'tür ki Ar-Ge stoğunun değerinin azalmasından ziyade değerinin artacağını ifade eder.

**Anahtar Kelimeler:** Özel Sektör Ar-Ge Stoku, Çok Faktörlü Verimlilik, Amortisman Oranı Tahmini, Görünürde İlişkisiz Regresyon, Üretim Fonksiyonu

## Introduction

The contribution of research and development (R&D) spending on multifactor productivity (MFP) growth has been examined by economists since Solow's (1957) decomposition of growth. Griliches introduced the R&D capital stock model in which the stock of a firm's technological knowledge itself is considered as a factor of production: existing stock of accumulated knowledge of firms is increased by the R&D activities, thus the production costs of existing goods and services decrease or the quality of products improves, i.e., increasing the productivity of firms (1979).

The new growth theories (see Romer, 1990) argue that R&D activities, in addition to increasing the economic performance of the undertaking companies, generate positive externalities to the other firms. Because of the partially "public-good" nature of knowledge, these R&D spillovers or technological externalities arise. Since the value society derives from R&D is much higher than that of the private sector which invested in R&D, government involvement in R&D is generally required. Therefore, the larger the difference between the private and social returns to R&D (spillovers), the stronger the case for government involvement seen. As a result, an increasing amount of resources have been devoted to R&D in developed countries by the governments and the private companies. Whether the returns on this investment justify the initial spending has been analyzed via economic analysis. For this aim, the relationship between R&D and productivity has been investigated at different levels of aggregation: economy, sector, industry and firm.

Economists have used two different methods while examining the contribution of R&D to economic performance: case studies and econometric analysis. Whereas identification of the effects of the benefits and costs of a specific innovation are the main themes of case studies, the econometric approach concentrates on the contribution of R&D to performance at a higher level of aggregation. The case studies are generally transparent and contain detailed information about one single firm or one single project. On the other hand, their lack of representativeness is considered to be one of the main disadvantages of case studies. As case studies tend to concentrate on selected successful projects, it is not possible to draw general conclusions from them.

Econometric studies also incorporate unsuccessful projects in their R&D expenditure or stock figures. The higher level of aggregation at the firm, industry or economy-wide level, coupled with the use of statistical techniques, makes it easier both to draw general conclusions from their findings and to calculate the external effect of R&D activities. However, the use of econometric techniques has numerous limitations. Many of them relate to availability of data. Measurement issues arise both in the case of output and in the case of inputs. There is a problem of "quality change" in the construction of price indices and, most importantly, there are no data on R&D capital stocks in the official accounts; therefore, R&D stocks generally have to be calculated by researchers. A significant difficulty raised by the production function framework is related to the construction of the R&D capital stock. The fact that there are no data on R&D capital stocks in the official accounts, which are equivalent to physical capital stock, raises the issue of obtaining an R&D capital stock estimates. In fact, Griliches (1979) suggested the perpetual inventory method for constructing a firm's knowledge capital<sup>1</sup>. Since then, it is the most commonly used method. Under this methodology, the R&D capital stock is calculated as the sum of the value of capital stock in the previous period, net of any depreciation that has occurred and the level of R&D expenditure in the previous period. However, this formulation comes with significant drawbacks. First, the magnitude of the depreciation rate is unknown. Then, Coe and Helpman (1995) argue that the initial R&D capital stock figures are quite sensitive to the growth and depreciation rates used. Finally, the assumption implies that, independently of whether R&D is carried out or not, every year a constant percentage of the R&D capital stock becomes obsolete. Most economists would argue that knowledge does not depreciate in such a mechanic way. Thus, it is likely that using the perpetual inventory method to measure capital stock figures may lead to results which are misleading.

Most empirical studies that investigate the role of knowledge on multifactor productivity concentrate on various measures of R&D as the sources of productivity. In this paper, while constructing R&D capital stock we used R&D flow data or R&D expenditures performed at business sector only. In other words,

<sup>1</sup> R&D capital stock, a firm's knowledge capital, and knowledge stock is used interchangeably for the rest of the study.

we calculated depreciation rates for one source of knowledge generating sector that is business sector<sup>2</sup>. On the other hand, empirical studies rarely allow for other determinants of productivity that emerges from theoretical models. There might be some omitted variables, and moreover these variables could be important if domestic multifactor productivity of countries seems to be sensitive to the factors other than stock of knowledge. In addition to omitted variables issues, the existing literature mostly estimates the fixed effect models with the implication of parameters of multifactor productivity relationships are homogeneous across the sample countries. However, countries may exhibit great difference in their productivity level, stock of R&D capital, etc. In such situation, the assumption of homogeneous productivity relationships across countries might be quite strong and it is unlikely to hold. Thus, searching for an omitted variables and dropping the assumption of parameters of multifactor productivity relationship is homogeneous across the countries are the differences we apply from the previous studies.

Considering the depreciation rate puzzle for constructing R&D capital stock, the aim of this study is to propose another method to construct R&D capital stock and estimate returns to knowledge stock simultaneously in a production function approach with grid search methodology using given depreciation rates ranges from -20% to 20%. By doing that our aim is to show that knowledge stock generated through R&D expenditures will be effective in the future innovations. In addition, we will also argue that the difference between the depreciation ratio that provides the maximum value of log of the likelihood function and that of conventional theories assume<sup>3</sup> (e.g. 10%) will be significant.

In order to find an appropriate depreciation ratio, then to construct R&D capital stock and finally to decompose the MFP as the source of knowledge and other competing theories, second section gives some discussions about how the depreciation rate for R&D

capital stock may be estimated. Section 3 begins by analyzing the methodology, data and other competing theories of MFP. Then, the formula we applied in order to attain R&D stock is introduced. The section closes with representing some descriptive statistics about reasons for dropping the homogeneity assumption. Section 4 reports the findings of the study and 5<sup>th</sup> section concludes.

## Depreciation Rate Estimation: The Empirical Framework

A corollary that using R&D intensities (R&D expenditures as a % of GDP) as a proxy for domestic technological knowledge to explain the cross-country differences in the multifactor productivity appear rather problematic, because it does not capture the substantial differences in their stock of knowledge. Therefore, it is better to calculate the stock of R&D then estimate private or social returns to R&D<sup>4</sup>. However, computing net rate of return or interpreting shadow value of the R&D stock required an assumption about the private depreciation or obsolescence of the assets generated by the R&D investment. But, determining the suitable depreciation rate is difficult for two reasons. According to Hall (2007) appropriate depreciation rate will change slowly over time. She argues that acceptable depreciation rate is determined by in addition to a firm's and its competitor's behavior, progress of public research and science. Another difficulty is related to the lag structure that conveys the relative contribution of past and current research development levels to R&D capital stock. As a result of not having enough natural experiments determining the lag structure of R&D for generating R&D capital stock will be very difficult. Since such lag structure is required to identify an appropriate depreciation rate Hall argues that it is really difficult to measure appropriate depreciation rate (2007).

Following Hall's argument about determining the appropriate depreciation rate, there are few studies tried to estimate the depreciation rate at the business level and industry level. Four types of empirical specifications are used to estimate R&D depreciation rates—production functions, amortization models, patent renewal models, and market valuation models.

2 Other sectors or institutions considered to be knowledge generator via performing R&D are public sector, universities, non-profit organizations and the knowledge generated in foreign countries.

3 Problem with the calculating the R&D stock capital from flow of R&D expenditures is problematic because one has to make an assumption about the unknown depreciation rates of R&D capital. Generally, empirical studies construct to R&D capital stock using the perpetual inventory method with the assumption of depreciation rates ranges from 5% to 15%.

4 The term "social" is used because the analysis we performed at the aggregate level. It implicitly measures the direct impact of R&D (i.e. the internal return at the firm level) and the externalities (i.e. the inter firm R&D spillovers) generated by innovative activities.

Hall (2007) clearly illustrates the some of the issues associated with the estimating R&D depreciation rates using a production function by discussing the types of identifying assumptions that are often needed to separately identify R&D depreciation rates. The first of these models assume that firms exist in a perfectly competitive market place that Hall mentions is inconsistent with the notion of R&D is often conducted to generate monopolistic returns. The second assumes that the output elasticities of ordinary capital and R&D capital are proportional to their input shares, which Hall characterizes as a “heroic” assumption that also may introduce a notable amount of specification error into estimation results. Hall (2007) by using Compustat data for a large panel of the United States manufacturing firms between 1974 and 2003 period estimates an “implied depreciation rate” of -6% in a production function approach to measure the returns to R&D capital stock. She also after dividing the entire period into 6 different 5-year periods reports that “implied depreciation rates” are different for each 5-year period. For instance, “implied depreciation rate” is -17.8% for the 1979-1983 period, and -4.7% for the 1999-2003 period. The important point for the estimated negative values for depreciation ratio implies that knowledge generated via R&D expenditures appreciates rather than depreciates. In the same study Hall also estimates R&D depreciation rates from a model related to the market value of the firm. Her estimates in this model is different than what she found using the production function approach. She estimates that R&D depreciation ratios ranging from 20 to 40 percent depending on the period.

Nadiri and Prucha (1996) also apply production function approach to estimate depreciation ratio for R&D capital stock by using a factor demand model for US total manufacturing sector. They estimated a depreciation rate of 12%.

Estimated depreciation rate of Bernstein and Mamuneas (2006) are also based on the production function approach. Authors made assumptions about future price expectations while estimating depreciation ratios; however, it is unclear how much specification error these assumptions may introduce into the estimates. In addition, some economists have more broadly argued that many of these models may inappropriately model the role of R&D in production by treating it in the same as ordinary capital. In particular, since R&D capital does not lose value

in the same manner as physical capital (wearing out in general use in production), some argue that R&D capital should be treated as factor that increases the production possibilities faced by a firm rather than an input in production.

Results from amortization models, such as those presented in Lev and Sougiannis (1996) and Ballester, Garcia-Ayuso, and Livnat (2003), are based on more general set of models that attempt to explain the returns on R&D investment. However, the resulting estimates are subject to similar concerns as those raised about results from production function models. For instance, Lev and Sougiannis are based on an assumed relationship between the amortization rate of R&D capital and earnings that these assets generate. The results are also based on the assumption that operating income serves as a good proxy for R&D benefits. While Lev and Sougiannis estimate a depreciation rate of 15% percent for 825 U.S. firms over the period of 1975-1991, Ballester, Garcia-Ayuso, and Livnat estimate the depreciation rate as 12% for 625 U.S. firms between 1985 and 2001.

Another model used to estimate depreciation rate is the patent renewal model, such as those presented in Schankerman and Pakes (1986). These models estimate the rate of obsolescence with R&D capital by using information on renewed patents to estimate a model in which the firms maximize the present discounted value of their returns to R&D investment. Yet patent renewals are not necessarily good measure of the value of the knowledge created by R&D because the value of this knowledge may not be well approximated by the price of the renewal. Even when attempts are made to address this consideration, another limitation is that not all R&D activity is associated with the filing of patents. Authors report a depreciation rate of 25% over the period of 1930-1939 for France, UK, Netherlands, and Switzerland.

Comparison of the studies that estimated depreciation rates at the industry and all R&D level shows that estimated depreciation rate ranges between -12% and 40%. There is no consensus about which depreciation ratio would be “appropriate” to calculate R&D capital stock, and then private or social returns to R&D can be estimated.

In this study different from previous studies we propose another way to construct R&D capital stock and estimate social return to stock of R&D within the



model with given depreciation ratio. Since the discussion of studies about the estimation of “appropriate” depreciation rate gives rates ranges from -17.8% (Hall for the period 1979-1983 using production function approach) to 46.9% (Hall using market value approach), we estimated a model that also allows us to use negative depreciation rates, in other words appreciation<sup>5</sup>.

## Methodology and Data

R&D is considered as a significant source of technical change. *Frascati Manual* (OECD, 1993) defines R&D as “comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge to devise new applications” (p. 29). R&D, however, is not the only source of MFP changes. Other activities such as education and learning by doing are important sources of MFP growth in modern, industrial economies. Moreover, education and learning by doing can increase economic performance through an improved ability to absorb new knowledge coming out of domestic R&D. In a production function approach the following system of equation is generally referred in order to evaluate the contribution of R&D to output growth:

$$Y = MFP \cdot F(H, K) \quad (3.1)$$

where  $Y$  is the output,  $H$  is the stock of private labor measured in hours worked,  $K$  is the stock of private capital,  $MFP$  states the current state of technological or scientific knowledge (multi-factor productivity). Growth of MFP can be written as a function of R&D stock generated through R&D expenditures performed in business sector and other competing theories given in the literature, as follows:

$$MFP = G(S, O) \quad (3.2)$$

$$\ln Y_{it} = \lambda_{it} + \ln A + \alpha_1 \ln H_{it} + \alpha_2 \ln K_{it} + \beta \ln S_{it} + \gamma \ln O_{it} + \varepsilon_{it} \quad (3.5)$$

5 Constructing R&D stock using perpetual inventory method requires calculation of initial capital stock using the average growth rate of R&D flow and depreciation rate. Since sample's first year is the starting point for R&D capital, in this method first year R&D expenditures is divided by the sum of average growth rate of R&D expenditures and the depreciation rate, given these sum of variables is greater than zero.

$S$  stands for the measure of accumulated R&D capital (as a proxy for the knowledge stocks generated by domestic firms),  $O$  is the other factors affecting multi-factor productivity. Finally, relationship between current R&D expenditures and R&D stock is given as:

$$S_t = \sum w_l I_{t-l}^{RD} \quad (3.3)$$

Where  $I^{RD}$  represents the gross R&D expenditures in period  $t$ , and  $w_l$  connects the level of past research to the current state of knowledge. For estimation purposes, a production function of a country  $i$ 's explicit structure is generally of the Cobb-Douglas type, which has a log-additive form, can be written as follows:

$$Y_{it} = A \exp[\lambda_{it}] H_{it}^{\alpha_1} K_{it}^{\alpha_2} S_{it}^{\beta} O_{it}^{\gamma} e^{\varepsilon_{it}} \quad i = 1, 2, \dots, N \quad (3.4)$$

where  $A$  is constant;  $\varepsilon_{it}$  is a multiplicative error term, reflecting the effects of unknown factors;  $\lambda$  is the rate of disembodied or autonomous technical change and  $\alpha_1$ ,  $\alpha_2$ ,  $\beta$  and  $\gamma$  are the parameters of interest, i.e. the output elasticities of labor, capital, R&D capital stock, and all other explanatory variables respectively. The estimation of these parameters may be calculated by taking the natural logarithm of equation (3.4), as follows:

the assumption of constant returns to scale with respect to labor and capital and payments of these traditional inputs are required for this analysis. In other words, the output elasticities with respect to labor (capital) are assumed to be equal to the labor (capital) cost share in total output and  $\alpha_2$  is equal to  $(1 - \alpha_1)$ . Rewriting equation (3.6) in the form of all competing theories of MFP in addition to sources of knowledge generated by business sector, we have the following equation:

It is common to drive an index of multi-factor productivity  $h$   $MFP$  from equation (3.5):

$$\ln MFP_{it} = \ln Y_{it} - \hat{\alpha}_1 \ln H_{it} - (1 - \hat{\alpha}_1) \ln K_{it} = \lambda_t t + \beta \ln S_{it} + \gamma \ln O_{it} + \varepsilon_{it} \quad (3.6)$$

$$\begin{aligned} \ln MFP_{it} = & \lambda_t t + \beta_1 \ln S_{it} + \beta_2 \ln G_{it} + \beta_3 \ln H_{it} + \beta_4 \ln L_{it}^l + \beta_5 \ln M_{it}^h + \\ & \beta_6 \ln X_{it}^h + \beta_7 \ln F_{it}^l + \beta_8 \ln F_{it}^o + \beta_9 \Delta U_{it} + \varepsilon_{it} \end{aligned} \quad (3.7)$$

The variables (for country  $i$  and time  $t$ ) are defined as follows<sup>6</sup>:

$MFP$  is an index of multi-factor productivity of total economy.  $MFP$  is computed as the ratio of the domestic product of industry to the weighted sum of the quantity of labor and fixed capital stock, the weights being the annual labor cost share and the capital cost share, respectively as given in equation (3.6). 13 OECD countries were selected according to availability of multifactor productivity data and resources devoted to research and development between the periods 1985 and 2005. These countries are Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Spain, the United Kingdom and the United States. Data for  $MFP$  is obtained from the OECD productivity database.

$S$  denotes the source of knowledge, R&D capital stock performed at the business sector. Data on  $S$  for each sample country is constructed from the real R&D expenditures performed by the private companies. The stock measures are constructed the way we'll discuss in the next sub-section. Interpretation of point elasticity should take into account the fact that the explained variable is not output (or GDP of industry) but  $MFP$ . That means we capture the social excess returns to business R&D, and not the total effects on output growth (which includes the direct effect or private return also). R&D performed by businesses generates new goods and services, in higher quality of output and in new production processes. These are the sources of  $MFP$  growth both at the firm level and at the macroeconomic level. The influence of business R&D on productivity has been analyzed in voluminous empirical studies, performed at the all aggregation levels—business units, firm, industry

and country levels—and for many countries (particularly the United States). In view of the accumulating evidence from these studies, a consensus in the literature is that business R&D contributes to domestic productivity<sup>7</sup>. The source for R&D performed in businesses is OECD's R&D Database with the exception of the U.S. that is taken from the National Science Foundation. Finally, it is expected that  $\beta_1 > 0$

A measure of public infrastructure related physical capital is denoted by  $G$ . Theories of public infrastructure argue that the "quality" and the "size" of the public infrastructure affect  $MFP$  and growth through cost reduction and/or improved specialization. The final report to the President and Congress of the National Council on Public Works Improvement (1988) emphasizes the significance of infrastructure to economy: "The quality of a nation's infrastructure is a critical index of its economic vitality. Reliable transportation, clear water, and safe disposal of waste are basic elements of a civilized society and a productive economy. Their absence or failure introduces an intolerable dimension of risk and hardship to everyday life, and a major obstacle to growth and competitiveness" (p. 1). While, Aschauer (1989), Munnell (1990), Berndt and Hanson (1992), and Nadiri and Mamuneas (1994) raised arguments for positive and significant impact of public infrastructure on  $MFP$ , Tatom (1991), Holtz-Eakin (1994), and Evans and Karras (1994) reported either non-significant contribution or negative impact of public infrastructure on  $MFP$ . Since the stock of public infrastructure is not available, it is proxied by the stock of public's physical capital. It is constructed from government's gross fixed capital formation following the perpetual inventory method with 5% depreciation rate. Data is

6 For simplicity we will drop the country  $i$  and time  $t$  subscripts for the rest of the chapter.

7 However, there are a few exceptions to this consensus. Panel studies on firm and industry level data (Griliches and Lichtenberg, 1984; Jaffe, 1986; Bernstein, 1988) report that R&D elasticities are often statistically insignificant.

taken from the OECD Economic Outlook Database (No. 82, 2007). Even though empirical studies are mixed we expect a positive impact of infrastructure on multifactor productivity on theoretical grounds; thus

$$\beta_2 > 0.$$

$H$  represents the stock of human capital, which is proxied by the average years of education for the age group 25 to 64. According to Bassanini and Scarpetta (2002) there are practically and theoretically better reasons to use a stock variable (average years of education) instead of a flow variable (e.g., school enrolment rate) to measure the impact of human capital on productivity and growth. First of all, quality of data on enrollment rates are generally lower than years of education, and to see the impact of changes in enrollment on growth one needs long lags, which are difficult to accommodate in our framework since we work on relative to shorter time span. Second, the alternative to using changes in years of education as a proxy for the accumulation of human capital is not suitable, as it refers to a net investment in human capital rather than the required measure of gross investment. Finally, reverse causality problems are less severe when a stock measure is considered. Data for average years of education of the population aged from 25 to 64 is obtained from Arnold, Bassanini and Scarpetta (2007), and it is expected that  $\beta_3 > 0$ .

$L^1$  is the life expectancy at age one. In general, life expectancy is a proxy for good health and desirable performance of nations. Barro and Sala-i-Martin (1995) state that "higher life expectancy may go along with better work habits and higher levels of skills" (p. 432). In this study we used life expectancy at age one, instead of life expectancy at birth, because differences in reporting the infant mortality across the countries. According to Healy (2006), in the United States, prematurity or size is not considered when counting the births. In other words, all births are considered as alive if they show any sign of life. On the other hand, European countries have different constraints to count a birth as alive, otherwise they don't report newborn babies, and thus they will have lower mortality rates compared to the United States. For instance, in Germany, fetal weight must be at least 1 pound to count as a live birth; in other parts of Europe, such as Switzerland, the fetus must be at least

12 inches long, in Belgium and France, births at less than 26 weeks of pregnancy are registered as lifeless. Moreover, in some countries babies who die within the first 24 hours of birth are not reliably registered. Since probability of dying in every age group is a part of life expectancy calculations for those ages and the discrepancies in registering live births across countries, using life expectancy at birth may not be good indicator for cross-country comparisons. Thus, life expectancy at age one is used in this study. However, we don't have available data for all the sample countries in this study. Thus, we used a formula that with data available for life expectancy at birth and for infant mortality, it is possible to calculate life expectancy at age one<sup>8</sup> (Morris, 1979). Data for life expectancy at birth and infant mortality rates are taken from OECD Health Database (2007). Eventually, we use calculated life expectancy at age one data for all countries and expect  $\beta_4 > 0$ .

Keller (1998); Grossman and Helpman (1991); Coe and Helpman (1995); van Pottelsberghe and Lichtenberg (2001) are all argue that imports are also another way of technology diffusion, and are denoted by  $M^h$ . Countries engage in imports benefit from international knowledge spillovers. Since, recent literature on this issue emphasize the significance of trade in differentiated capital goods, we use a ratio of high tech imports of goods to total imports of goods to capture this effect and expect  $\beta_5 > 0$ .

$X^h$  stands for the ratio of high tech exports to total export of goods. The theory of "learning by exporting" argues that domestic companies increase their specialization and multi factor productivity in the process of meeting the high product quality imposed by the foreign customers. Bernard and Jensen, after examine the relationship between exporting and firm performance, report that produce more than twice as much output and are 12%-19% more producti-

8 The formula used to approximate the life table values at age one was:

$$LE_1 = \frac{LE_0 - 1 + q(1-k)}{1-q}$$

where  $LE_1$  is the infant mortality rate per thousand live births;  $k$  is the average survival period (0.2 years) during the first year;  $LE_0$  is life expectancy at birth; and  $q$  is the infant mortality rate per thousand live births.

ve (1999). Wagner (2002), Delgado *et al* (2002), and Greenaway and Keller (2007) are also reported results that show exporting is MFP improving. Therefore, we expect  $\beta_6 > 0^9$ . Relevant series to compute the ratios is obtained from OECD's STAN Indicators database<sup>10</sup>.

Another variable discussed in the literature among the competing theories of multifactor productivity is foreign direct investment (FDI)<sup>11</sup>. Since FDI has two different angles,  $F^I$  stands for foreign companies invest in domestic country (inward FDI), and  $F^O$  is domestic companies invest abroad (outward FDI), both type of FDI is included the model. Despite mixed empirical results (see Keller and Yeaple (2003) for a survey), we expect  $\beta_7$  and  $\beta_8$  to be positive. The data for both FDI stock variables are obtained from the United Nations Conference on Trade and Development (UNCTAD) database.

Finally, a control variable that is added to model is the annual growth of the rate of unemployment,  $\Delta U$ . It is a stylized fact that productivity is pro-cyclical, and such periods of economies must be captured; therefore it is expected that  $\beta_9 < 0$ . Data for the unemployment rates of nations are obtained from OECD Economic Outlook Database (No. 82, 2007).

**Formula Used in Construction of R&D Stocks**

Going back to equation (3.3), and assumption that there exist a relationship between the current level of technological knowledge stock,  $S_t$ , and an index of current and past levels of research and development expenditures,  $w_l I^{RD}$ , where  $w_l$  is a lag polynomial, describing the relative contribution of past and current research development levels to  $S_t$ , and  $l$  is lag (backward shift) operator, equation (3.3) can be rewritten as:

$$S_t = (w_0 + w_1 l + w_2 l^2 + \dots) I_t^{RD} = w_0 I_t^{RD} + w_1 I_{t-1}^{RD} + w_2 I_{t-2}^{RD} + \dots \tag{3.8}$$

Since we have available data on the flow of business performed R&D and it's known that some rate of depreciation of knowledge links flow of R&D to the stock of R&D, equation (3.8) can be rewritten as the stock of

R&D at time  $t$ ,  $S_t$ , the flow of R&D at time  $t$ ,  $I_t^{RD}$ , and since they are related by the rate of depreciation of knowledge ( $\delta$ ) over time in the following equation:

$$S_t = I_t^{RD} + \frac{I_{t-1}^{RD}}{1 + \delta} + \frac{I_{t-2}^{RD}}{(1 + \delta)^2} + \frac{I_{t-3}^{RD}}{(1 + \delta)^3} + \dots + \frac{I_{t-l}^{RD}}{(1 + \delta)^l} \tag{3.9}$$

Measuring R&D capital stock  $S_t$  requires both knowledge of its private depreciation or obsolescence rate, and time lag of  $l$ , again where  $l$  is the number

of years it takes for a flow of R&D spending to become useful in private production (or to go through the phase of generating marketable products or process).

In case of deciding the depreciation rate to construct R&D capital stock, previous studies used the perpetual inventory method, which requires calculation of benchmark R&D capital stock, which calculated as dividing the first year R&D expenditure of the sample period by sum of average growth rate of R&D expenditures during the period, and assumed depreciation ratio  $\left( \frac{I_1^{RD}}{(g + \delta)} \right)$ . Assumed depreciation ratio used in cross-country studies ranges from 5% to %15. After calculating the benchmark year R&D stock, the rest of the sample period's R&D stock is calculated by sum of previous year R&D stock after discounting for depreciation plus the current year's R&D expenditures in the economy.

9 We use the ratio of high tech exports to total exports assuming that it captures the quality aspects of exports better—for instance, improving quality (productivity) through exporting. In order to export high tech goods the exporting country needs to be technologically efficient and hence more productive. Similarly, a ratio of high tech imports to total imports is used to capture the productivity effect emanating from imports.

10 OECD's definition of high tech industries includes the following International Standard Industrial Classification, Revision 3 (ISIC): Aircraft and spacecraft; Pharmaceuticals; Office, accounting, and computing machinery; Radio, TV and communication equipment; Medical, precision and optical instruments (OECD, 2005).

11 See Lipsey (2002) for a review.



$$S_t = (1 - \delta)S_{t-1} + I_t^{RD} \quad (3.10)$$

However, perpetual inventory methodology does not consider the idea of negative depreciation ratio or another words appreciation. In other words knowledge generated through R&D expenditures become obsolete, and will not contribute the society's general stock of knowledge in a relatively short period of time. Moreover, the calculation of benchmark R&D capital stock calculation requires  $(g + \delta)$  being greater than zero, otherwise we might run into negative stock of R&D capital values. Finally, perpetual inventory method does not consider the fact that the research and development process takes time and that current research and development may not have an impact on measured productivity. Griliches (1998) argue that completion of an R&D project, then turning into a product of this initial R&D project, and then seeing the revenue generated from this R&D project for the companies may take longer lags. Thus, we constructed the R&D capital stock using the formula (3.9) with the depreciation rates ranges between -20% and 20% with 28-year embodiment lag from R&D expenditures.

Bayoumi, Coe, and Helpman (1996) argue that it takes 80 years to see the full effect of initial R&D investment. In other words, if we increase the current R&D expenditures by 10 percent, in about 80 years the R&D capital stock will reach the full amount of its steady-state increase of about 10 percent. In particular, about half of the steady-state value of the R&D capital stock is obtained after 15 years. Thus, our approximation of taking 28 years of lags might be apposite. Thus, we started R&D stock calculations from 1953, because the availability of R&D expenditure data for the United States. The year 1981 when the R&D expenditures data starts for the remaining

OECD countries. Since previous studies show that the United States is the major generator of R&D spillovers all over the world, and other countries uses the knowledge generated through R&D expenditures in the United States, R&D performed in the United States will influence the multifactor productivity of the other OECD countries considered here, and it will not effect our econometric estimates. Thus, we calculated R&D capital stock for each country starting at 1953, and used zeros for the OECD countries other than the US between 1953 and 1981.

### Countries Differ in Their Economic Conditions (Dropping the Homogeneity Assumption)

Figure 1 plots the log of MFP for the countries and shows that they exhibit substantial fluctuations between countries. For instance, the US multifactor productivity shows a modest upward trend throughout the sample period. The UK multifactor productivity slows first 5 years of the period, and then improves somewhat since 1992. German total factor productivity shows noticeable increase during the later part of the 80s, but it stagnates from the early 1990s. Plots for Canada, Denmark, and Netherlands appear flat throughout. French and Spanish total factor productivity also appears to be flat during the sample period. Spanish productivity seems to be recovering from its decline starting at 1997. Ireland's multifactor productivity shows a rapid rate of growth from its low base. The Finnish total factor productivity trend appears similar to the Irish but the Finland's total factor productivity growth rate is smaller. Multifactor productivity of Italy and Belgium exhibits similar patterns of slow growth. Japanese multifactor productivity increased quite rapidly during the first five years of the sample period then appears quite similar to the other major developed nations.

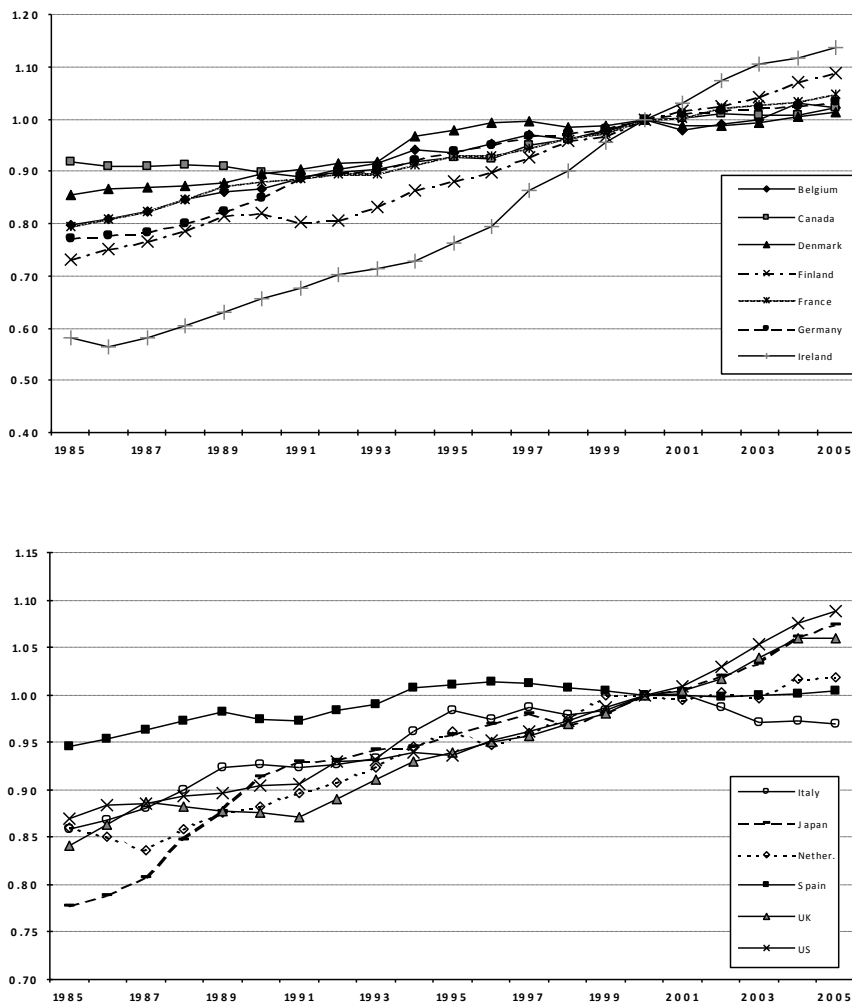


Figure 1. Multifactor Productivity (logarithms): Period 1985-2005

In addition, Table 1 presents some summary statistics of data set we applied in this study. Descriptive statistics show heterogeneity in the growth rates of multi-

factor productivity and their determinants across the sample OECD nations.

Table 1. Descriptive Statistics (1985-2005 mean value)

	MFP <sup>1</sup> Growth rate	Business R&D <sup>2,3</sup>		Human Capital <sup>4</sup>		Public Infrastructure <sup>2,5</sup>		High-technology <sup>2,6</sup>		Outward FDI <sup>2,7</sup> Stocks	Inward FDI <sup>2,8</sup> Stocks	Life Expectancy <sup>9</sup> AGE <sup>11</sup>
		Expenditure	Intensity	Stocks	Intensity	Stock	Exports [Intensity]	Imports [Intensity]				
Belgium	1.2	3.0	1.2	10.4	1.9	59.8	1.9	18.7 [9.5]	20.2 [10.8]	117.1	148.8	76.4
Canada	0.5	7.3	1.0	12.8	2.6	157.5	2.6	20.8 [7.5]	35.8 [14.2]	184.5	181.4	77.7
Denmark	0.9	1.6	1.2	11.3	1.8	22.8	1.8	5.8 [10.3]	5.6 [11.3]	31.7	31	75.4
Finland	2	2.0	1.6	11	3	37.1	3	5.9 [12.7]	5.1 [14.6]	26.7	15	75.8
France	1.4	19.2	1.4	10.5	3.2	393.5	3.2	50.9 [14.4]	48.4 [14.3]	294.7	217.9	77.4
Germany	1.6	31.1	1.6	12.6	2.1	414.3	2.1	77.9 [13.4]	75.7 [14.7]	341.4	182.7	76.1
Ireland	3.2	0.6	0.7	9.9	2.8	26.8	2.8	21.9 [32.3]	11.7 [21.1]	29.9	81.4	75.5
Italy	0.6	7.7	0.6	8.8	2.6	379.1	2.6	24.5 [8.0]	34.8 [12.1]	139.7	100.6	77.6
Japan	1.7	63.0	2.1	11.8	5.1	1561.3	5.1	86.3 [26.6]	39.6 [13.5]	182.5	27.2	79.3
Nether.	0.8	4.0	1.0	11.4	3.2	109.2	3.2	36.2 [14.0]	37.0 [15.9]	233.7	170.7	77.1
Spain	0.4	3.3	0.4	7.9	3.8	223.4	3.8	9.9 [5.5]	22.6 [12.3]	117.6	161.2	77.6
UK	1.1	17.0	1.3	11.4	1.8	238.3	1.8	61.9 [17.6]	61.8 [16.5]	509.5	317.2	76.3
US	1.1	155.1	1.9	12.7	3.4	2402.8	3.4	178.5 [21.1]	191.1 [17.7]	937.3	763.1	75.7
Mean	1.3	24.2	1.2	11	2.9	463.5	2.9	46.1 [14.8]	45.4 [14.5]	242	184.5	76.8

1. Multifactor Productivity. 2. Billions of constant 2000 PPP US dollars. 3. Intensity (R&D expenditures performed at business sector as a % of GDP). 4. Stock of human capital is proxied by the average number of years of schooling of the population from 25 to 64 years of age. 5. Public infrastructure is proxied by the stock of public physical capital stock.

6. Intensity (high-technology imports (exports) as a % of total imports (exports)). 7. Stock (Outflow of foreign direct investment). 8. Stock (Inflow of foreign direct investment).

9. Life expectancy at age 1.

The average annual growth rate of MFP ranges between a minimum 0.4% (Spain) to a maximum of 3.2% (Ireland); the sample mean is 1.3%. The multifactor productivity of the United States and the United Kingdom increased by around 1.1% during the period 1985-2005. On the other hand, Japan, Germany and France experienced higher growth rates of 1.4% or above (1.7%, 1.6%, and 1.4% respectively).

The business sector R&D intensity (business sector R&D expenditures to GDP ratio) gives a sample mean of 1.2%, but it varies between a minimum of 0.4% to a maximum of 2.1%. Across the sample OECD countries considered in this study Japan has the highest intensity ratio of R&D performed by business sector. Then, the United States has the second highest business sector intensity ratio of 1.9%. Germany, Finland (1.6% each), France (1.4%), and the United Kingdom (1.3%) come behind the United States respectively. On the other hand, Spain is the country that performs the smallest intensity of business sector R&D (0.4%).

The stock of human capital appears to be the lowest in Spain (7.9 average years of schooling of the population from 25 to 64), while Canada has the highest (12.8) years of schooling; sample mean is 11 years. The United States and Germany follows the Canada with 12.7, 12.6 years of schooling, respectively. Public infrastructure intensity (government's infrastructure related gross fixed capital formation to GDP ratio) varies between a minimum of 1.8% (the United Kingdom) and a maximum of 5.1% in Japan. The cross country-intensity of high-tech exports differs by a factor of nearly 6 [from Spain (5.5%) to Ireland (32.3%)]. On the other hand, Belgium's intensity of high-tech imports (10.8%) is smaller by a factor of 2 than Ireland (21.1%).

A corollary to comparison of intensity measures is that; although number of nations in the sample has comparable (in some cases almost same) intensity measures, the differences in their R&D expenditures that generate stocks of knowledge are quite large. The reason for that is the significant dissimilar size of OECD economies. For instance, Japan has a higher intensity of business sector R&D (2.1%) than that of the United States (1.9%). However, the United States' expenditures for business sector R&D are nearly 2.5 times more than that of Japan. Since a way of increasing knowledge stock arise from R&D performed in different sectors, the higher R&D expenditures will

generate higher stock of knowledge for the total economy. Eventually, R&D performed by business sector will result in new goods and services, in higher quality of output and new production processes. These are the sources of productivity growth at the firm level and at the macroeconomic level. Another pair of countries that are Belgium and Denmark has almost identical business sector R&D intensity of 12%. But, Belgium's business sectors R&D expenditures nearly twice the amount of that of Denmark. Consequently, stock of knowledge generated through business sector R&D will be higher in Belgium compared to Denmark. Assuming everything else constant, Belgium economy will have higher growth rate of multifactor productivity.

If the relationship is linear between knowledge stocks generated through R&D performance of domestic economies and their positive and significant contribution to multifactor productivity, then Germany should have higher multifactor productivity growth for the sample period considered. Table 1 is also shows that Germany has experienced higher multifactor productivity growth (1.6%) then the United Kingdom (1.1%) and supports the idea that using the R&D intensities to explain cross-country differences in multifactor productivity could be misleading.

The analysis of descriptive statistics for the sample of OECD countries considered above suggest that domestic multifactor productivity levels may be affected by the factors other than knowledge generated through R&D stock. Competing theoretical models of productivity argues that there are significant productivity differences across the countries and R&D may not be the only source that affects the productivity.

## Empirical Results

Mosteller and Tukey (1977) argue that an econometric strategy would be to consider reasonable alternatives to see whether the results are sensitive to technique or specification. However, during the process of reporting the results we only reported specifications of the equation (3.7). We estimated the model using the Seemingly Unrelated Regression (SUR) estimator that corrects for the contemporaneous correlations of the error term across the nations. In addition, SUR allows us to estimate country specific parameters for the countries considered in this study. We have argued that assuming homogenous parameters and ad-



justment dynamics across all the sample countries in the panel would not be suitable because of the heterogeneity in multifactor productivity levels (or growth rates) and its determinants among the sample nations. In this context, the best empirical strategy would be to conduct country-by-country econometric analyses of equation (3.7). However, we only have 21 observations for each country and twelve theoretical determinants of multifactor productivity. Unfortunately, not having enough observation coupled with the number of the explanatory variables, degrees of freedom problems wouldn't let us conduct country-by-country time series analysis. Another reason to use Seemingly Unrelated Regression is that the disturbances in equations for each country at a given time are likely to reflect some common immeasurable or omitted factors, and therefore, could be correlated. When such correlations exist, it may be more efficient to estimate all equations jointly. Plus, Breusch-Pagan LM test shows that errors are contemporaneously correlated, hence we used the SUR rather than ordinary least square (OLS).

Finally, since we construct the R&D stock and estimate the returns to R&D simultaneously, our results will depend on the, using Hall's notation, "implied depreciation rate" (2007, p. 36). The estimated parameters would be the ones where estimated log of the likelihood function of SUR reaches maximum or minimum point for given depreciation ratios during the grid search process. In the calculations of business sector R&D capital stocks we assumed depreciation rate is constant across countries and during the sample period of this study<sup>9</sup>.

Figure 2 plots the estimated log of the likelihood function values (MLE) against the varying depreciation rates in percentages. Since estimated log of the likelihood function reaches maximum where depreciation rate is -3%, we can also conclude R&D stock appreciates.

Parameter estimates for each country, after constructing R&D stocks with -3% depreciation rate, are reported in table 2. In this specification country-specific point estimates of business sector R&D stock,  $\frac{\partial MFP}{\partial S^b}$ , show that six of the countries in the sample lose significant impact of business R&D stock

upon their multifactor productivity. These countries are Belgium, Denmark, Finland, Ireland, the Netherlands and the UK. Comparison of point-elasticity estimates of business R&D stock with the simple model for the remaining countries shows that they all have higher point estimates with the exception of Canada where the estimated point elasticity is -0.06 and statistically significant. On the other hand, point estimates of the United States (0.58), Spain (0.224), Japan (0.263), Italy (0.231), Germany (0.108) and France (0.201) are all statistically significant and have a productivity increasing impact in these economies.. Finally, results show that cross-country parameter heterogeneity does exist.

We find a negative and statistically significant effect of the stock of public physical infrastructure on their domestic multifactor productivity for four countries (France, Ireland, Italy, and Spain); insignificant for seven countries; and positive and significant for Germany (0.407). Therefore, government's infrastructure related government physical capital stock does not appear to effect domestic multifactor productivity of the sample countries with the exception of Germany. Seven countries in the sample (Canada, Denmark, Finland, Germany, Ireland, Netherlands, and the United Kingdom) show statistically significant effects of human capital on their domestic total factor productivity, however the estimated point elasticities,  $\frac{\partial MFP}{\partial LE^1}$ , are so large that are puzzling and difficult to explain so are the negative and significant impact of stock of human capital on Italian and Japanese multifactor productivity.

Point estimates of life expectancy at age one with respect to multifactor productivity,  $\frac{\partial MFP}{\partial LE^1}$ , also show confusing results similar to human capital stock. Estimated coefficients are very large (e.g., 2.35 for the United Kingdom, -4.581 for Netherlands), and its impact on domestic multifactor productivity is statistically negative for five countries (Denmark, Germany, Japan, Netherlands, and Spain). While the United Kingdom, Belgium, and Finland have statistically significant and positive estimated point estimates at 10% or better significance level, remaining five countries (the United States, Canada, France, Ireland, and Italy) have insignificant parameter estimates. The point elasticity of high-tech imports,  $\frac{\partial MFP}{\partial M^h}$ ,

9 All estimations are done using SHAZAM 10.1 software program

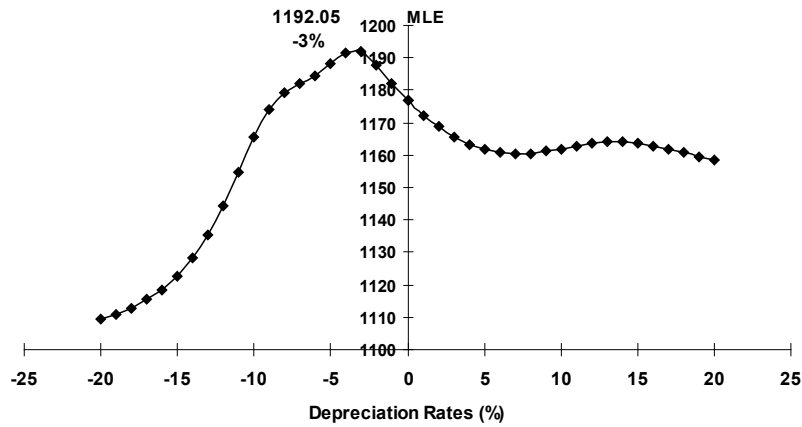


Figure 2. Grid Search for Depreciation Rate: Augmented Model

Table 2. Country-Specific Multifactor Productivity Estimation Results, in Log-Levels\*

	S <sup>b</sup>	G	H	L <sup>l</sup>	M <sup>b</sup>	X <sup>h</sup>	F <sup>l</sup>	F <sup>o</sup>	ΔY
BELGIUM	0.066 1.266	-0.205 -1.228	-0.356 -1.353	2.165 1.892	-0.137 -2.740	0.111 2.012	0.105 3.444	-0.085 -2.257	-0.054 -1.709
CANADA	-0.060 -1.996	-0.019 -0.149	1.712 2.270	-0.377 -0.368	0.024 0.765	0.002 0.098	0.054 2.213	0.040 1.238	-0.055 -3.532
DENMARK	0.025 0.837	-0.309 -1.607	2.838 2.268	-1.765 -1.960	-0.073 -1.766	0.107 2.807	-0.046 -2.662	0.032 1.780	-0.072 -5.708
FINLAND	0.014 0.356	0.209 0.956	0.493 2.530	1.710 1.946	-0.033 -0.866	0.006 0.235	-0.009 -0.449	0.038 2.072	-0.053 -5.622
FRANCE	0.201 4.201	-0.404 -2.089	-0.366 -1.333	0.090 0.170	0.008 0.132	-0.113 -2.344	0.030 1.496	0.030 2.131	-0.059 -2.332
GERMANY	0.108 3.211	0.407 2.368	1.407 2.960	-2.189 -2.025	-0.188 -1.975	0.208 1.891	0.010 0.267	0.046 1.238	0.026 1.069
IRELAND	0.024 0.395	-0.291 -2.247	3.011 3.831	0.927 0.628	-0.250 -3.221	0.259 2.598	0.056 2.466	0.028 0.651	-0.035 -1.006
ITALY	0.231 3.945	-0.890 -3.131	-1.026 -3.663	0.780 0.883	0.002 0.033	0.054 0.935	-0.003 -0.148	0.025 0.730	-0.023 -0.331
JAPAN	0.263 7.850	0.280 2.673	-1.121 -2.214	-1.343 -2.378	-0.192 -3.445	0.022 0.360	0.006 0.502	0.019 1.428	-0.057 -2.138
NETHER.	-0.041 -0.527	0.137 0.432	2.283 1.505	-4.581 -1.965	-0.049 -0.480	0.062 0.552	0.082 0.868	-0.062 -0.516	-0.036 -0.937
SPAIN	0.224 4.436	-0.223 -2.877	-0.289 -1.266	-1.168 -1.928	-0.103 -3.766	0.031 1.657	-0.058 -3.549	0.000 -0.025	0.012 0.861
UK	0.029 0.911	-0.034 -0.390	0.401 2.023	2.351 2.659	-0.066 -1.798	-0.036 -0.958	-0.039 -1.676	0.053 3.106	-0.055 -2.896
US	0.580 4.160	-0.135 -1.321	0.037 0.039	0.667 1.236	-0.066 -2.108	0.021 0.734	-0.014 -0.895	-0.033 -1.110	-0.022 -2.074
Mean est.	0.128	-0.114	0.694	-0.210	-0.086	0.057	0.013	0.010	-0.037

\*t-values are given under the estimated parameters

appears negative and significant for eight countries (Belgium, Germany, Ireland, Japan, Spain, and the United States at 5% or better significance level; the United Kingdom and Denmark at 10% significance level). The remaining five countries have statistically insignificant point estimates of  $\frac{\partial MFP}{\partial M^h}$ .

Five countries (Belgium, Denmark, Germany (at 10% significance level), Ireland, and Spain (at 10% significance level)) show positive and significant influence of high tech exports on their domestic multifactor productivity. Among the remaining sample countries, only France has the negative and statistically significant point elasticity of high tech exports,  $\frac{\partial MFP}{\partial X^h}$ . The impact of high tech exports on domestic multifactor productivity is not statistically important for the remaining seven countries. In general, the technologically advanced countries may not achieve multifactor productivity gains through learning-by-exporting; on the other hand, relatively less advanced OECD countries, such as Ireland, Spain, Belgium, may do so.

The pattern of mixing results of estimated partial elasticities throughout the model can also be seen on the effects of inward foreign direct investment (FDI) and outward foreign direct investment on domestic multifactor productivity. An investigation of the estimated partial elasticities of inward FDI,  $\frac{\partial MFP}{\partial F^i}$ , shows that three countries (Belgium, Canada, Ireland) have a positive and significant effect; three other countries (Denmark, Spain, the United Kingdom (at 10% significance level)) exhibit negative and statistically important effects; and for the rest (Finland, France, Germany, Italy, Japan, Netherlands, and the United States) the impact is not statistically significant. In the case of outward FDI, four countries [Denmark (at 10% significance level), Finland, France, and the United Kingdom] exhibit positive and statistically important effect on domestic multifactor productivity. For these countries, technology outsourcing is productivity enhancing. While Belgium's estimated point elasticity of outward FDI,  $\frac{\partial MFP}{\partial F^o}$ , has a negative impact on her multifactor productivity, the rest of the sample countries do not exhibit statistical significance impact of outward FDI on their domestic multifactor productivity.

Finally, point estimates for the business-cycle control variable, growth of unemployment rate, confirms that productivity is pro-cyclical and economic downturns reduced multifactor productivity. Even though we find that Germany and Spain have unexpected signs for the growth of unemployment rate, the point estimates are not statistically significant. The remaining countries in the sample have the expected sign; however, point estimates of growth of rate of unemployment,  $\frac{\partial MFP}{\partial \Delta U}$ , are not statistically significant for the countries; Ireland, Italy and Netherlands. The remaining eight countries (the United States, the United Kingdom, Japan, France, Finland, Denmark, Canada, and Belgium) exhibit an important impact of growth rate of unemployment rate on domestic multifactor productivity.

The results exhibit that introducing the competing theories of productivity to the basic equation (4.1) may cause the explanatory power of business R&D stock on multifactor productivity for some countries in the sample during the period 1985-2005. In addition, several other determinants analyzed by economic theory such as human capital, infrastructure, FDI, high tech imports and exports, life expectancy bring into important country-specific effects on multifactor productivity. These impacts are beyond those of the business sector R&D. Results also imply that only changes in the unemployment growth rate do seem to have consistent estimates over the OECD countries we covered in this study.

As a robustness check, we also compared our results with the estimates of ordinary least square. OLS estimates also exhibit the similar pattern compared the SUR estimates; however, with OLS we are unable to control the business cycle shocks<sup>10</sup>. Both OLS and SUR estimate the depreciation ratio as -3% for augmented model. Growth of unemployment rate is the only variable that we would be able to generalize according to discussions we have previously. Plus, P-VALUE of near zero for basic specification and that of 0.04332 for augmented model we received as a result of Breush-Pagan LM test shows errors are contemporaneously correlated. Thus, the SUR estimates parameters more efficiently than OLS. Finally, we also check the significance of "implied depreciation rates" we estimated where the value of log of the li-

10 Results are not shown here, but it is available on request.

**Table 4. Robustness of Estimated Depreciation Rates Compared to 10%**

BUSINESS R&D STOCK ESTIMATES				
<i>Estimated Model</i> : $\ln MFP_{it} = \lambda_i + \beta_1 \ln S_{it} + \beta_2 \ln G_{it} + \beta_3 \ln H_{it} + \beta_4 \ln L_{it}^1 + \beta_5 \ln M_{it}^h + \beta_6 \ln X_{it}^h + \beta_7 \ln F_{it}^I + \beta_8 \ln F_{it}^O + \beta_9 \Delta U_{it} + \varepsilon_{it}$				
Depreciation Rate	$\delta$ (-3%)	$\delta$ (0%)	$\delta$ (10%)	$\chi^2$ (1 d.f) (5% significance level)
LLF estimates	1192.05	1176.897	1161.956	
Differences		15.153	30.094	3.84146

likelihood function reaches maximum with the values of log likelihood function with the conventional 10% depreciation rate used to construct R&D capital stock. Table 4 gives the results for differences between these estimates for both specification of model.

While estimated log of the likelihood function value is 1161.956 with the conventional 10%, this value is 1192.05 when the depreciation rate is -3%. Therefore, likelihood ratio test with  $\chi^2$  distribution with one degree of freedom shows that the difference between two depreciation rates is highly significant. This also imply that conventional depreciation rates such as 10% or 15% do not reflect the idea of public good characters of intangible capitals, specifically business R&D stock we used in this study.

**Conclusion**

In this study, knowledge-multifactor productivity relationship was re-examined in a panel of 13 OECD countries for the period 1985-2005. Compared to related analysis of knowledge-productivity relationship, we specifically focused on the possibility of omitted variables in determining productivity, the ignorance of the idea that productivity relationship is heterogeneous across countries, and suggest a different methodology to estimate depreciation rate while constructing R&D capital stock. Even though previous methods permit for country-specific fixed and country-invariant-time effects, they imply that MFP relationships are homogenous across the sample of countries. In other words, they cannot address the potential cross-country heterogeneity in slope parameters. Hence, we used Seemingly Unrelated Regression Estimator (SURE) that differs from the method

of pooling time-series or cross sectional data to correct for potential correlations between the error terms associated for the 13 countries. In addition, SURE allows us to consider cross-country heterogeneity, because of the assumption that each cross-section unit has a different coefficient vector. An empirical analysis of this nature has both theoretical and practical applications. At the theoretical level, importance of competing theoretical models can be revealed if they pass the empirical investigation of the MFP determining factor. In practice, policy makers may be better informed by the identification of the key drivers of the MFP and their parameters.

The problem with the constructing R&D capital stock is that it requires knowledge of unknown depreciation or obsolescence rate, and time lag that represents the number of years for a flow of R&D to become useful in private production (or to go through the phase of generating marketable products or processes). Previous empirical studies assumed depreciation rates ranges between 5% and 15% to construct the R&D capital stock using the perpetual inventory method. On the other hand, results of a few papers that estimate the private depreciation rates at the firm level and industry level showed that “implied depreciation ratio” ranges from -minus 17.8% to 46.9% - depending on the time, industry and estimation technique. On the other hand, we estimated the depreciation rate through a grid search different from previous studies considering depreciation rates changes between -20% and 20% by constructing the R&D capital stocks with 28-year embodiment lag from R&D expenditures and estimating their social rate of returns simultaneously using SURE. We estimated depreciation rate (rather appreciation) of -3% with the augmented model. Re-



manding that we estimated social returns to R&D, and the negative “implied depreciation rate” implies that the positive externalities and the intertemporal spillovers generated through new innovations are higher than the negative effect of business-stealing effect in which innovations destroy the social returns from previous innovations. Moreover, estimated negative implied depreciation rate represents the public good nature of knowledge.

The results show that the business R&D stock is statistically significant and have a positive impact on MFP for the countries France, Germany, Italy, Japan, Spain and the United States. On the other hand, remaining countries’ business R&D stocks lose their explanatory power on the MFP with the augmented model in which we use all other explanatory variables with business R&D stock. In fact, Belgium, Denmark, Finland, Ireland, the Netherlands, and the United Kingdom are the countries that represent their business R&D stock are not a factor in determining the MFP. Another country is Canada, which has a negative and statistically significant estimated parameter after introducing the competing theories of MFP. Estimated point elasticities vary across the countries representing that cross-country heterogeneity is important. Competing theories of MFP also follows the unexpected coefficient estimates as the stocks of R&D capital. The public infrastructure does not seem to enhance the MFP. Its effects are insignificant for seven countries and significantly negative for France, Ireland and Spain. Japan is the only country that has the expected positive effect for the public infrastructure. The stock of human capital gives conflicting results, in other words difficult to generalize for the countries we consider in this study. Plus, the estimated coefficients are very large. In addition to having large coefficient estimates, its negative and significant sign for Italy and Japan is also puzzling. Life expectancy at age one represents the similar pattern with the stock of human capital. Estimated coefficients are very large, and whether their statistically positive or negative impact on MFP brings more puzzling results. Furthermore, other determinants – ratios of high tech imports and exports, inward FDI, and outward FDI – of MFP show mixed results. They appear statistically significant in several cases but the signs of their coefficients do not always confirm the theoretical pri-

ors. Finally, business cycle control variable, growth of unemployment rate, has negative and statistically significant impact on domestic MFP for the majority of the countries in the panel (11 out of 13 countries have the negative sign and 8 of them are statistically significant). In other words, economic shocks have MFP reducing impact on domestic economies.

Finally, the likelihood ratio test shows that the difference between the “implied depreciation rate” we estimated considering the values of maximum log likelihood function for all specifications and those with the traditional 10% depreciation rate is statistically significant at any significance level. This implies that considering the R&D stock capital similar to the tangible capital stock could be misleading, especially at the cross-country studies in which social returns to generated knowledge or new ideas are higher than obsolescence of the benefits we receive from the previously generated ideas.

In general, since the way we estimated the model, we only used the business R&D stock, one can argue that collinearity could be a problem, but we can add other domestic knowledge generating factors such as university R&D stock, government R&D stock, and foreign R&D stocks to our model. Then, it would be interesting to see the results. We also assumed constant depreciation rate for the countries in this paper. Following our results that countries are different in their economic conditions, constant depreciation rate assumption would also be changed for future studies. Plus, examining how the depreciation rate changes in different periods during the time period considered would be interesting to see. Our results generally contradicts with the theory in estimating the impact of domestic sources that effects domestic MFP, such as, stock of human capital and life expectancy. Another way to estimate the model may be by defining the cross-country heterogeneity in MFP parameters. In this type of modeling, country-specific parameters assumed to be linear function of the country specific mean or per worker stocks of types of knowledge stocks. Eventually, the MFP could be estimated by cofactor of previous years’ MFP levels and mean or per worker stocks of business R&D stock. Considering the cross-country heterogeneity in this manner would in our research agenda for the future.

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