

Introducing R&D Capital Stock into National Accounts. The Case of Japan.

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Abstract.

This thesis introduces knowledge capital into national accounts, measures its returns and examines the impact of including R&D capital stock in a growth accounting exercise for the case of Japan. Using data from the Main Science and Technology Indicators-OECD I estimated Japan's R&D capital stock. I went on to use this as a proxy of knowledge capital and recalculated national accounts for the period 1981–2012 finding that the real GDP level, total capital stock and private investment rate were 3%, 7% and 1.5% higher on average, respectively. These results evidence the importance of capitalizing R&D into national accounts. In the second part of the research I adjusted GDP's income side components by including R&D capital stock and found an innovative method to estimate a lower bound R&D rate of return that resulted near 7%. I used a growth accounting exercise with multiple types of capital to study the importance of R&D capital accumulation on output growth.

1. Introduction.

The question I examine in my analysis is how important knowledge capital is in explaining economic growth applied to the case of Japan. The first part of the thesis is concerned with correctly accounting for Research and Development (R&D) capital stock and calibrating its rate of return and a second part is centred on measuring how including R&D capital stock changes the way we account for economic growth.

The main motivation that drives my work is the idea that knowledge capital has not been correctly tabulated in national accounts. This affects estimations of economic activity and our understanding of the relationship between knowledge and economic growth. Some characteristics of knowledge capital, such as its intangibility, non-rivalness and partially excludable consumption, make it difficult to estimate. This is probably why resources devoted to knowledge generation have to date been computed as expenses instead of investment.

My thesis is also motivated by the fact that knowledge has only recently been included as a potential factor of economic growth and that it has gained importance with the enlargement of knowledge intensive economic activities. Although technological change and innovations have marked the changes in economic performance throughout history, we are only recently finding ways to incorporate the creation of technology into our theoretical and empirical analysis. Classical economists originally focused on land and labour as the main drivers of growth. Later, as a consequence of industrial transformation physical capital gained importance in detriment of land, and more recently knowledge, through human capital accumulation, has gained importance in the economic research agenda as a growth component.

At the same time, the general acceptance of R&D activities as a proxy for knowledge generation efforts has made standardized data on resources devoted to R&D available. This availability of detailed data series has allowed for the realization of this thesis.

The main contributions of this work are threefold. On one hand, I adjust national accounts by estimating the knowledge capital stock using resources devoted to R&D activities as a proxy for investment in knowledge. This implies estimating the capital stock series of the different economic agents in the economy and adjusting Gross Domestic Product (GDP) components both from the expenditure and income side. The exercise is applied to Japan, one of the more successful economies in the post-WWII period with high investment rates in R&D and excellent data availability. I cover the period from 1981 to 2012 which is when Japanese economy showed the highest levels of resources devoted to R&D (as a ratio of GDP) and data is available.

Secondly, I calculate the R&D rate of return as a residual from macroeconomic identity equations using national accounts. This methodology, which I have not seen in the literature I have reviewed, will give a lower bound of the R&D rate of return from a macroeconomic approach. The reason why R&D rate of return measured with this methodology should be considered a lower bound is because a part of the R&D capital returns have been double accounted for as profits from physical capital investment.

A third contribution of this thesis is an estimation of how much of economic growth can be explained by R&D capital accumulation. For this part, I perform a growth accounting exercise with the estimated knowledge capital stock and the adjusted national accounts.

I found that Japanese Real GDP was 2.9% higher on average after capitalizing R&D and adjusting national accounts in the period 1981-2012. Recalculations also show that national capital stock and the private investment rate were on average 6.7% and 1.5% higher, respectively, and, additionally, the rate of return from R&D investments was on average at least 7.3%. In the growth accounting exercise I found that R&D capital accumulation helps to explain only a marginal portion of GDP growth, being considerable smaller its effect in economic growth when comparing with physical capital and labour accumulation.

The remaining thesis is structured as follows. In the next section, I present a summarized theoretical framework related to knowledge capital and a summary of methodologies and empirical results used when adjusting national accounts, capitalizing R&D, estimating returns and performing growth accounting exercises with different types of capital. In the following section, I present the data used, then detail the computations performed and assumptions considered. I go on to describe the results obtained and comment the robustness checks I have performed. Lastly, I conclude on how introducing knowledge capital affects national accounts and how important knowledge capital is in explaining economic growth applied to the case of Japan.

2. Theoretical framework and empirical evidence.

2.1. Endogenous growth models.

During the 1980's growth theorists gave birth to the endogenous growth models which theoretically sustain the importance of human capital accumulation, innovations and knowledge in economic growth.

Aghion and Howitt (2009) present the different endogenous growth models such as the AK and other more sophisticated ones. Among those, the authors present a one-sector Schumpeterian model where there exists an intermediate good produced by a competitive monopolist with certain technology and labour which is used in the final good production. Each period there is one person (or researcher) who has an opportunity to attempt an innovation in the production of the intermediate good, with certain probability. If succeeds, becomes the monopolist in the production of the intermediate good. If not, the previous monopolist keeps producing with the same technology and the sector does not grow. In this model, the success of innovating is uncertain but more research increases the probability to innovate successfully. This model

predicts that in the long-run output growth rate will equal the frequency of innovations times the size of innovations.

Aghion and Howitt (2009) extended the previous model to a multi-sector one allowing for a continuum of intermediate innovating sectors with a single research monopolist in each one. Innovation takes place in each sector as in the previous one-sector model. Now, by the law of the large numbers, the lack of innovation in one sector will be offset by “good luck” in others and this will determine the endogenous aggregate growth rate.

This thesis contributes to better understand the relationship between knowledge and economic growth from an empirical approach such as endogenous growth models does from a theoretical approach.

2.2. R&D in national accounts.

In this thesis I will consider knowledge capital as the result of capitalizing resources devoted to R&D activities, following the System of National Accounts (SNA) 2008. By doing this, I am considering that R&D activities imply an effort to generate a stock of national knowledge which can promote technological change or the adoption of external innovations for national purposes. Defining knowledge capital in this way implies that resources devoted to R&D activities are similar to durable goods which last more than one period, such as physical capital investment¹.

Research and development is creative work undertaken on a systematic basis to increase the stock of knowledge, and use this stock of knowledge for the purpose of discovering or developing new products, including improved versions or qualities of existing products, or discovering or developing new or more efficient processes of production (SNA 2008).

¹ Throughout this thesis I will use the terms “knowledge capital” and “R&D capital” indistinctly.

Following a background paper done by the United States (US) Congressional Budget Office (CBO 2005) it can be seen that R&D activities are usually classified in three categories. These are basic research activities which imply mainly theoretical investigation in order to increase the state of knowledge; applied research which involves investigation activities but with a specific use in mind; and experimental development which is the use of existent knowledge looking to produce new products and services or improve processes or the production of existent products.

The output of R&D capital, that is technological change, is characterized by for having a high level of uncertainty about its market and social value, for being intangible, non-rivalrous and partially excludable on its consumption, which makes it harder to measure.

It must be said that the SNA is the main statistic framework which defines a standardized methodology for national accountability and periodically recommends improvements. As an example and related with intangible assets, the SNA 1993 made relevant recommendations about how to tabulate software and programming copyrights, promoting its later inclusion as assets, instead of expenses, in national accounts.

Nowadays, resources devoted to R&D activities are considered expenses in the national accounts, implying that they are consumed in one period, ignoring the existence of knowledge capital accumulation.

The SNA update published in 2008 was the first time that capitalizing R&D was recommended, a similar suggestion which was also made by the European System of Accounts (ESA) in 2010. The specific recommendation was to value R&D capital according to its market value and if it did not exist one, summing its costs. Until 2014, few countries had implemented this recommendation, among them Australia, Canada, United States (US) and United Kingdom (UK) (Ker 2014) but this was not the case of Japan (Japan Statistical Yearbook 2015).

In the case of US, different efforts and approximations for capitalizing R&D can be found over recent years. An example of this is the US Bureau of Economic Analysis (BEA) R&D Satellite Account (Lee and Schmidt, 2010). This Satellite Account was an earlier effort to estimate how US GDP would change if R&D were to be considered as investment, instead of expense. The BEA R&D Satellite Account was first estimated in 2007 and updated in 2010, covering the period 1959–2007, but R&D was not effectively considered an asset until 2013 GDP's estimation (BEA, 2014). Similar efforts can be seen by the Office for National Statistics (ONS) of UK where R&D was first capitalized in 2014's GDP estimation (Ker 2014 and Abramsky 2014).

In both cases, US and UK national statistics, tabulating resources devoted to R&D as assets derive in an increase of GDP's estimation. For the UK, the increase of current GDP estimation for the period 2000-2013 was between 2.6% and 4.6%, depending on the year (The Blue Book 2014 Edition) whereas for the US the increase was 3%, on average (BEA 2014).

Previously, Fraumeni and Okubo (2005) had estimated a preliminary and explorative satellite account for the US in which they explained that resources devoted to R&D activities have traditionally been tabulated as expenses. This means that R&D resources were considered intermediate goods and services and because of that they were not included in the national accounts expenditure side components, underestimating GDP. Knowing the amount of resources that different agents allocate in R&D activities makes it possible to adjust the GDP components by capitalizing R&D. The amount of resources that are financed by the private sector should be included in the Investment (I) component meanwhile those activities that are financed by the public sector, not considering public companies, should be included in the Government (G) component.

Starting off with Net Exports (NE) and Gross Investment in R&D (GIRD), the main adjustments will be the following:

$$GDP_t = C_t + I_t + G_t + NE_t$$

$$I_{Adj,t} = I_t + GIRD^{Priv}_t$$

$$G_{Adj,t} = G_t + GIRD^{Gov}_t$$

$$GDP_{Adj,t} = C_t + I_{Adj,t} + G_{Adj,t} + NE_t$$

With respect to the income side components of the national accounts, Fraumeni and Okubo (2005) suggest that only changes to the proprietor's income (PI) should be made. Considering Gross Domestic Income (GDI), Labour Income (LI), Capital Depreciation (D), Indirect Taxes less Subsidies (IT), Direct Return of R&D Investment (DRRD), the main adjustments will be the following:

$$GDI_t = LI_t + PI_t + D_t + IT_t$$

$$PI_{Adj,t} = PI_t + DRRD^{Gov}_t + DRRD^{Priv}_t$$

$$GDI_{Adj,t} = LI_t + PI_{Adj,t} + D_t + IT_t$$

It must be said that when doing these adjustments the authors are considering certain assumptions as for example that no portion of the R&D direct return is already considered in the unadjusted proprietor's income. Also, that indirect return is already included in the consumption component.

The BEA R&D Satellite Account adjusted US national accounts for the period 1959–2007 find that capitalizing R&D will imply, on average, a 3% higher real GDP, when comparing to the non-adjusted real GDP (Lee and Schmidt 2010). Adjusting national savings estimations showed that savings rates, as a percentage of national income, would have been 2% higher, when comparing with the non-adjusted values.

Fraumeni and Okubo (2005) also present empirical studies² which focused on how R&D expenses were conformed and found coincidence on the fact that between 45% and 50% of expenditures were devoted to human resources, 45% to inputs and only 5% were devoted to capital goods.

2.3. R&D capital stock.

In order to estimate the R&D capital stocks some decisions about the parameters to be used have to be made. First of all, a depreciation rate has to be considered. Li (2012) developed a specific model to estimate depreciation rates from 10 R&D intensive industries that were included in the BEA R&D Satellite Account and found that the average depreciation rate was over 15% and varies between industries from 11% to 38%. CBO (2005) compiled a large number of studies related to R&D and productivity growth in the US and show that most of the researches considered used a 15% geometric depreciation rate. Goto and Suzuki (1989) estimated the rate of obsolescence of R&D capital stocks in different Japanese manufacturing industries and show that it ranges between 7% and 25% for those industries more technologically intensive. Fraumeni and Okubo (2005) constructed the preliminary R&D Satellite Account for the US using a geometric depreciation rate of 11% and ran robustness checks. Following Fraumeni and Okubo (2005) I will use an 11% geometric depreciation rate in the main calculations of this work and I will perform robustness checks changing this assumption.

With respect to the price index used to deflate R&D investment flows, Fraumeni and Okubo (2005) used a private fixed non-residential investment price index to deflate and when performing robustness checks used an information-processing equipment and software price index. Lee and Schmidt (2010) made reference to the price indexes used by the BEA to estimate the R&D Satellite Account and explained that the input price index used to deflate was

² Fraumeni and Okubo (2005) present results from Dougherty, Inklaar, McGuckin and Van Ark (2004), from Jaffe (1973) and Griliches (1984).

similar to others “used for government and other hard to measure services in the national accounts”. Goto and Suzuki (1989) considered industry-specific input price indexes for their study over Japanese manufacturing industries. In the main scenario of this thesis I will use a manufacturing products price index which resumes the price evolution of the most technological intensive Japanese sectors.

Another important aspect when estimating R&D capital stocks is the capital lag used. This refers to the gestation period which is the time between when investment is performed and capital is activated. When estimating physical capital stocks the gestation lag considered is mainly zero, but because of the R&D-specific characteristics some researchers have used other values. Fraumeni and Okubo (2005) used one-year lag and made robustness checks with three, five and seven years, showing minor changes in their results. Goto and Suzuki (1989) used industry specific gestation lags that were between two and three years, depending on the industry. Li (2012) considered two scenarios: one with a gestation lag of zero years and the other with a two-year gestation lag; and concluded that the use of a zero-year gestation lag is more appropriate. As when tangible capital is estimated, I will assume a zero year lag gestation in the main calculations of this work.

According to Berlemann and Wesselhoft (2014), almost all estimations of capital stocks used the Perpetual Inventory Method (PIM) which is based on the fact that present capital stock is a function of capital stock, gross investment and capital depreciation in the previous year, as follows:

$$K_t = K_{t-1} + I_{t-1} - D_{t-1}$$

Depreciation is fixed capital consumption, via tear&wear and obsolescence, and results from multiplying the capital stock in the previous period by the depreciation rate. Assuming a geometric constant depreciation rate we find that:

$$K_t = (1-\delta)K_{t-1} + I_{t-1}$$

Repeatedly substituting the previous capital stock we have that:

$$K_t = \sum_{i=0}^{\infty} (1-\delta)^i I_{t-(i+1)}$$

The previous function shows that the actual capital stock depends on historical investments. If the historical capital stock series is incomplete, which usually happens, they need to be estimated assuming an initial stock level.

$$K_t = (1-\delta)^{t-1} K_0 \sum_{i=0}^{t-1} (1-\delta)^i I_{t-(i+1)}$$

Berlemann and Wasselhoff (2014) explains that when not having the initial capital stock, one of the most frequently used approaches has been the Steady State Approach originally developed by Harberger (1978). This approach rests on a neoclassical growth theory framework. It considers that when the economy is in its steady state, capital grows at the same rate as output.

$$g_Y = g_K = \frac{K_t - K_{t-1}}{K_{t-1}} = \frac{I_t}{K_{t-1}} - \delta$$

$$K_{t-1} = \frac{I_t}{g_Y + \delta}$$

An important caveat about this approach is its dependency on the amount invested and the growth rate during one particular year. In order to avoid the bias this could introduce, average investments and average output growth rates over a number of years are considered. Moreover, Berlemann and Wasselhoff (2014) recommend to follow De la Fuente and Domenech (2000) using an average investments growth rate instead of the steady state growth rate.

2.4. R&D returns.

When estimating R&D returns a number of issues must be considered. First of all, the difference between direct and indirect return (or spillover). Following CBO (2005), when referring to direct return I will consign profits obtained by the agent who financed the R&D activities and owns the

output obtained from those R&D activities. This agent could be specialized in performing R&D activities or could be, for example, a larger company with a specific R&D department. In any case, I will consider the direct return to be the profits obtained from the output of these R&D activities which derived into a technological change. It is worth noting that the scale-up of a technological change and the profits that this scale-up could generate are not part of the R&D returns.

With indirect return or spillover I will refer to the profits derived from the R&D outcomes which are not property of the financing agent and instead benefit others. According to Nadiri (1993) “the spillover effects of R&D are often much larger than the effects of own R&D at the industry level”.

An example to clarify the differences between direct and indirect returns or spillovers can be seen when considering the development of a new medication by a pharmaceutical company. The R&D activities are financed by the company and performed by the internal R&D department. The development of a new medication is the R&D output and the value of the new medication patent can be seen as the direct return of the pharmaceutical company. This direct profit could also be obtained if instead of selling the patent, the company decides to produce, blister and commercialize the new medication. In this case, the R&D direct return will probably muddle up with the producing and commercializing returns. Moreover, spillovers will occur mainly in two situations. One hand if it is possible for other companies to imitate this new medication and gain profits from it and on the other hand if this new medicine derives in health cost's reduction for society.

Another aspect to take into account when analyzing R&D returns is the kind of R&D activities that generate these returns. As it was mentioned, R&D activities can be classified in three groups: basic research, applied research and experimental development; and each of these generally have different outcomes and returns. Basic research is supposed to produce lower

economic returns, to the converse applied research and development are expected to generate higher returns.

When considering the financing and performing agents of R&D activities they are mainly classified by industry, government, the higher education sector and the private non-profit sector where public companies are classified as industry. Considering this classification, it is seen that basic research is mostly performed and financed by the government, higher education sector and private non-profit sectors whereas applied research is mixed and development is concentrated in industry (MSTI Volume 2014/2 2015).

According to the CBO (2005) and Nadiri (1993) reviews, studies that try to estimate R&D rates of return can be classified mainly in two categories depending on whether the analyzed effect of R&D is on output (production function studies) or on production costs (cost function studies), the former being more abundant in the literature. These reviews also show that most production function studies are done for US and Japanese firms and industries. The studies present more than 20 R&D direct rates of return estimations which ranged from 0% to 56%.

Moreover, Goto and Suzuki (1989) used the production function approach in order to estimate R&D direct rates of return. They estimated the following regression for the different industries analyzed:

$$\dot{P}TF/P_{TF} = \beta_0 + \beta_1 * (\dot{R}/Q)$$

with the growth rate of total factor productivity (TFP) as the dependent variable, \dot{R} net R&D investment, Q the industry value-added and β_1 net R&D rate of return. Using this methodology, the authors estimated an average R&D direct rate of return of 40% for seven Japanese manufacturing industries.

With respect to spillovers, Goto and Suzuki (1989) present two possible methodologies for estimating it. On one hand they present a methodology based on transaction flows which

implies constructing a technology-flow matrix that show how R&D embodied in intermediate and investment good flows from one industry to other. The other methodology presented was originally suggested by Griliches (1979) and developed by Jaffe (1986) and is based on the technological distance between industries. It must be said that most estimations of R&D spillovers use one of this two methodologies.

Fraumeni and Okubo (2005) present the results of different empirical studies which estimate R&D rates of return and showed that direct rate of return ranged between 7% to 43% whereas spillovers ranged between 11% and 147%. What is interesting in this article is that the authors differentiated rates of return of the industry sector from that of the government and higher education sector, the first one being higher than the latter one and the same was considered for spillovers. These differentiated rates of returns reflect the different objectives among sector when financing R&D activities.

2.5. Growth accounting.

According to Barro (1999), growth accounting methodology first developed by Solow (1957), could be seen as a preliminary step when analyzing the relevant factors of economic growth by tracing back changes in output to variations in factor inputs and a residual which measures technological change, institutions, X-inefficiency, omitted variables and other things. The standard growth accounting exercise uses a neoclassical production function

$$Y = F(A, K, L)$$

with A being technology level, K capital stock and L labour. Differentiating this equation with respect to time and dividing over by Y gives

$$\dot{Y}/Y = g_A + (F_K K/Y)(\dot{K}/K) + (F_L L/Y)(\dot{L}/L)$$

where F_K and F_L are the marginal products of capital and labour, respectively. Barro (1999) indicates that this equation is impractical because marginal products are unknown. Thus, when

computing growth accounting two simplifications are considered: first that A is neutral in the function F which means that

$$F(A, K, L) = A \cdot F(K, L)$$

and second, the marginal products can be calibrated with observed prices, i.e. the price of renting capital (r) and the wages (w). Including these assumptions and considering the technological growth rate as a residual we obtain

$$g_A = \dot{Y}/Y - (rK/Y)(\dot{K}/K) + (wL/Y)(\dot{L}/L) \quad (1)$$

which can be easily estimated.

Considering that $rK + wL = Y$ would be true if all income is distributed between capital and labour, which is the same as assuming that the exponents in a traditional Cobb-Douglas accumulates 1, so that

$$Y = A K^\alpha L^{1-\alpha}$$

Barro (1999) explains that finding values for equation (1) do not involve an econometric approach and could be computed directly for each period using time series data and extended with different kinds of capital and labour.

With respect to the inclusion of different types of capital and labour, the author presents a multiple types of factors model where the production function is

$$Y = F(A, K_1, K_2, L_1, L_2)$$

and the way to proceed is similar to that explained above but requires knowing the income share of each type of capital and labour. The key aspect of this method is to correctly discriminate the different types of capital and labour in the data and calibrating the income shares associated to each one.

The relevance of knowledge capital accumulation could be also estimated by econometric techniques. In that sense, Fraumeni and Okubo (2005) performed a growth accounting exercise with an econometric approach distinguishing R&D capital stock from other kinds of capital, in order to estimate the specific effect of R&D as an economic growth source. Before performing this extended growth accounting exercise, they adjusted both expenditure and income side national account components by capitalizing R&D. The specific equation regressed was the following, where the subscript O is used to indicate other kinds of capital different from R&D and RD the subscript used for R&D capital

$$\dot{Y}/Y = g_A + (r_{O}K_O/Y)(\dot{K}_O/K_O) + (r_{RD}K_{RD}/Y)(\dot{K}_{RD}/K_{RD}) + (wL/Y)(\dot{L}/L)$$

Barro (1999) indicate that regression approaches have certain disadvantages as for example that capital and labour accumulation should not be considered as exogenous from output growth, being the non-econometric approach preferable.

3. Data.

The R&D data used in this thesis was extracted from the MSTI – OECD data base. This database includes more than 100 series related with resources devoted to R&D for 34 OECD members and another seven non-OECD countries. According to the data description publication, MSTI Volume 2014/2 (2015), the data was collected from retrospective surveys to the agents performing R&D and presented according with the OECD standards for R&D data which are mainly included in the Frascati Manual (2002). The data covers the period 1981 to 2013 but because of the complexity of collecting it, values for certain years and countries are missing.

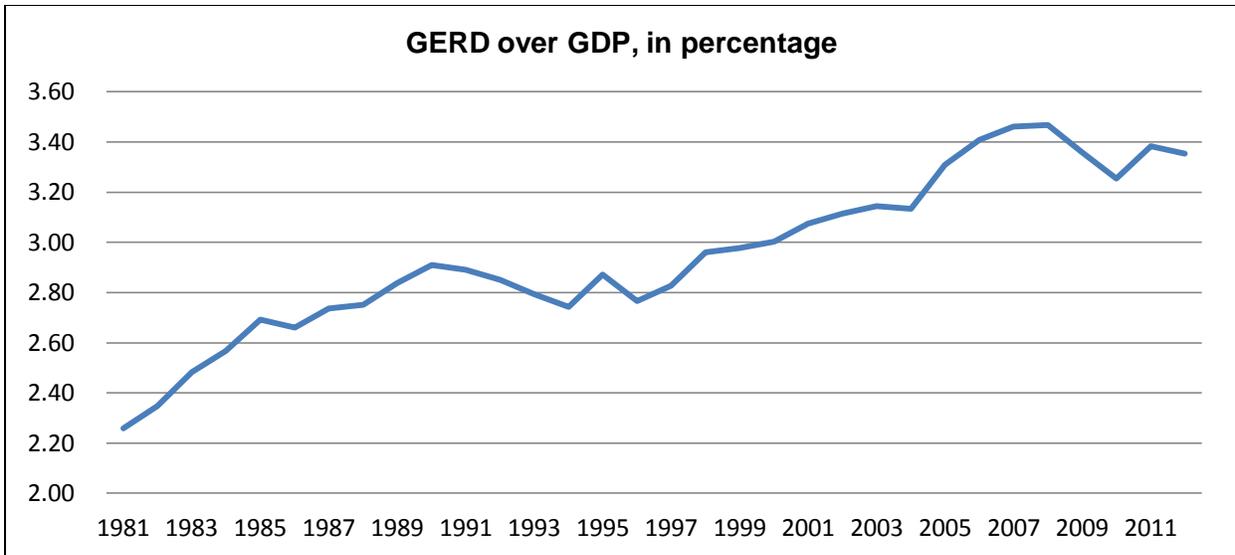
The main variable is the Gross Expenditure in R&D (GERD) which accumulates all resources devoted to R&D by each country in a corresponding year. Information about human resources involved in R&D activities is also presented, such as Total Personal and Total Researchers devoted to R&D activities, measured in full-time equivalent (FTE).

R&D resources are also classified according to the agent who performed the activities grouping into Business Enterprise sector (also called Industry; includes private and public enterprises as well as institutes working for those enterprises), Higher Education sector, Government and Private Non Profit sector.

GERD is also presented according to the agent who financed the R&D activities and the categories are Business Enterprise, Government, Other National Sources and Abroad. According to the MSTI Volume 2014/2 (2015), Other National Sources group Higher Education and Private Non Profit agents, and because of the small amount financed by each one the categories were combined.

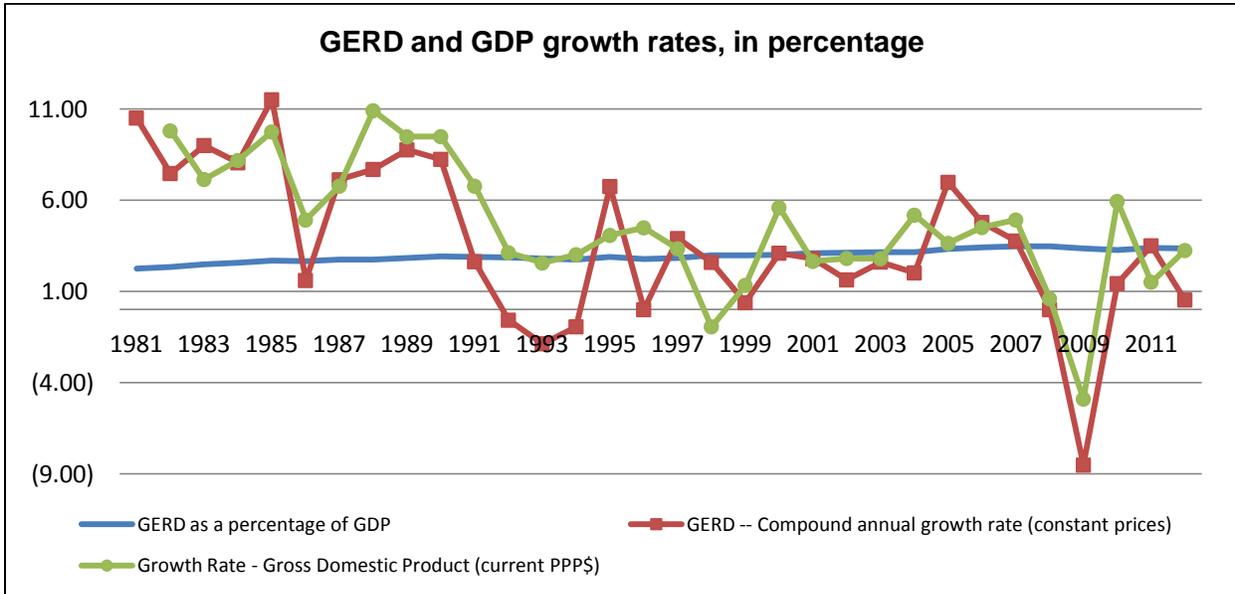
Looking at the GERD over GDP ratio as the main indicator of R&D efforts, we find that Japan is one of the countries which has devoted a large amount of its resources to R&D between 1981 and 2012 on average, only third to Israel and Sweden, countries which present missed values for a large number of years and variables.

Analyzing Japan's MSTI data, we can see that the GERD to GDP ratio increased from near 2.2% to near 3.4% over the 1981 to 2012 period. During the 1980's and between 1997 and 2007 this ratio showed a positive trend whereas in the periods 1990-1997 and 2008-2012 it was relatively constant.



Own elaboration. Data source: MSTI-OECD.

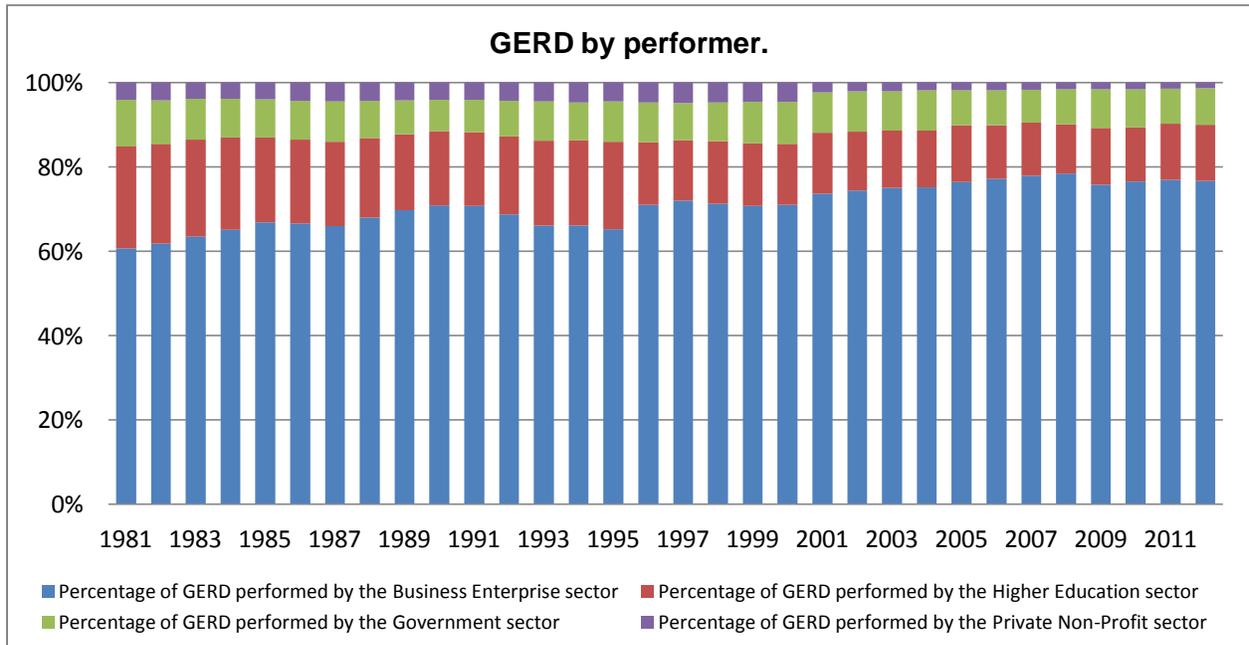
When comparing the GERD growth rate with the GDP growth rate it can be seen that GERD showed a pro-cyclical behaviour with the exception of the years between 1995 and 1997 when it briefly reverts to a counter-cyclical behaviour.



Own elaboration. Data source: MSTI OECD.

Analyzing expenditure by the different agents over the whole period, we can discern that 71% of the GERD has been performed by the Business Enterprise sector on average, while the Higher Education performed more than 16%, the Government 9% and the Private Non Profit sector

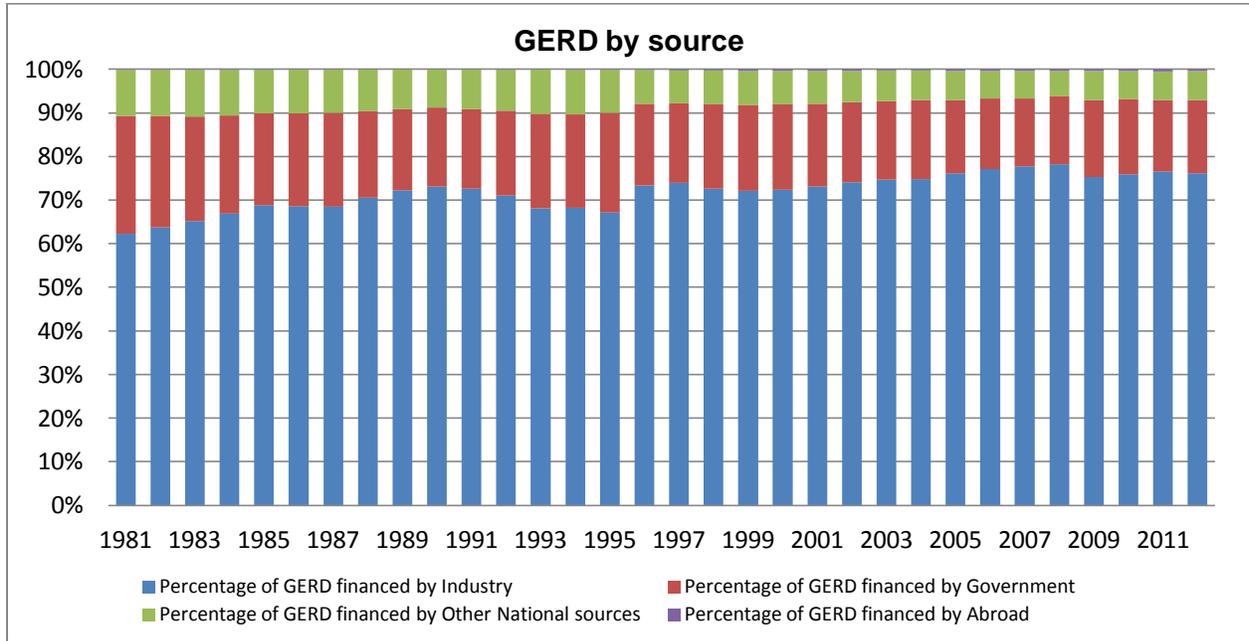
less than 4%. The high fraction of R&D financed by the private sector is a particular characteristic of Japan's economy. Comparing to the US and UK, it can be seen that public sources devoted to R&D explained a larger fraction of total resources (MSTI-OECD database). Analyzing the evolution of the performing sectors over the period examined, we see that Business Enterprise increased its share from 66% on average in the 1980's to 76% between 2001 and 2010 meanwhile the Higher Education decreased its share from 21% to 13% over the same periods. The Private Non Profit sector also experienced a decreasing trend in its performing share going from 4% in the 1980's to 2% between 2001 and 2010, while the Government share remained nearly constant.



Own elaboration. Data source: MSTI OECD.

Analyzing the financing agents of GERD a similar picture emerges. GERD financed by Industry was 72% on average for the whole period and increased from 68% in the 1980's to 76% in the period 2001–2010. Government financed 19% on average for the 1981–2012 period and its share decreased from 22% in the 1980's to 17% in the period 2001-2010. Other National

Sources financed 8% of GERD on average whereas R&D activities financed by Abroad were marginal and did not even reach 0.3% on average.



Own elaboration. Data source: MSTI OECD.

Comparing the information between funders and performers we find that the Industry sector financed more than 98% of its own GERD, whereas the Government financed its own R&D activities and also most of the GERD performed by the Higher Education sector.

Data related with Japanese national accounts, such as GDP’s expenditure and income side components as well as capital stocks, price indexes and labour accumulation were extracted from the 2015 Statistical Yearbook and Historical Statistics collected and published by the Japanese Statistics Bureau. Because some time series were not continued for the whole period of interest and are calculated with different conventions, they have been spliced using a common methodology for all series (Prados de la Escosura 2003).

In the period analyzed, Japan’s real GDP at 2005 prices grew on average 2.1% showing considerable differences throughout the period. Whereas in the 1980’s the economy grew at an

average 4.7% rate, in the 1990's it was 1.4% and from 2001 onwards the average growth rate was even lower reaching 0.7%.

The large growth rate experienced by Japan's economy during the 1980's confirmed its post WWII recovery becoming a high-income country. During the 1990's economic growth slowed explained mainly by a financial crisis related with the collapse of assets prices. From that onwards, price deflation hindered Japan's recovery and invoked expansionary policies taking interest rates near to zero. In 2005 evidence of recovery can be seen but this was negatively affected by the 2008 international crisis and 2011 Fukushima earthquake.

4. Re-estimation and analysis.

In this section I will describe the different procedures applied and assumptions considered in adjusting national accounts, estimating R&D capital stock, obtaining R&D rates of return and performing the comparative growth accounting exercise.

My first clarification is that all the R&D calculations performed in this thesis were done considering GERD according to its financing agent. Although there are empirical exercises based on the performer classification, such as Fraumeni and Okubo (2005), I base my choice on the principle that the economic agent who finances R&D activities is the one who defines to a large degree the kind of activities to be performed and the returns to be expected.

Moreover, considering the low amount of GERD that was financed by Abroad I decided to merge GERD Financed by Abroad with GERD Financed by Other National Sources in one new classification named GERD Financed by Others.

In a first step, I proceeded to deflate the GERD series using the Japanese Manufacturing Industry Products Price Index, with base year 2005, considering it is the most appropriate price index for deflating investment series. From now on I re-named the series which I worked with as

Gross Investment Research and Development (GIRD) instead of GERD and distinguished whether financed by Industry (Ind), by Government (Gov) or by Others (Oth).

In order to adjust the expenditure side of GDP estimation I proceeded in a similar way as Fraumeni and Okubo (2005) by aggregating GIRD in the Investment and Government components, as follows:

$$I_{Adj,t} = I_t + GIRD_t^{Ind} + GIRD_t^{Oth}$$

$$G_{Adj,t} = G_t + GIRD_t^{Gov}$$

$$GDP_{Adj,t} = C_t + I_{Adj,t} + G_{Adj,t} + NE_t$$

An important implicit assumption I make is that all direct and indirect R&D returns are already tabulated in the GDP expenditure side components. This is based on the idea that the returns that firms and the government obtain from R&D activities are already considered in the economy's available resources. Returning to the previous pharmaceutical company example, we can assume that the profits this firm obtains from patenting a new medication are not distinguished specifically as R&D profits but instead are contained within the company's returns, increasing shareholder's consumption if extracted as dividends (and thereby the national account's consumption component) or increasing investment (and thereby national account's investment component) if reinvested. In a similar way, the indirect profits obtained by the society (spillovers) due to the discovery of a new and assumedly cheaper medicine will derive into an increased of national consumption or savings (and investment) and lower work absence (increased production).

In order to estimate the R&D capital stock I had to take certain decisions about the parameters to consider. With respect to the depreciation I used a geometric 11% rate for the main computations in accordance with Fraumeni and Okubo (2005); this rate is within the range of values that Goto and Suzuki (1989) found as obsolescence rates in the Japanese economy.

Additionally, I have performed robustness checks to evaluate the sensitivity of my results to my proposed calibration of the depreciation rate parameter. With respect to the gestation period I considered no capital lag based on the assumption that knowledge generation is instantaneously: R&D activities are financed, performed and the knowledge capital is created, all in the same year. Although this is a strong assumption it is also commonly used when estimating physical capital.

For estimating the initial capital stock of the different financing sources I followed the Steady State Approach presented by Berlemann and Wasselhoft (2014). In order to avoid the bias introduced into the initial capital stock estimation by the values of a specific year and to avoid losing observations, I considered the average investment growth rate of the whole 1981 to 2012 period and the average investments of the 1981–1983 period, the formula being as follows

$$K_{1981}^i = \frac{\bar{I}_{1981-1983}}{\bar{g}_{1981-2012} + \delta}$$

where i the Industry, Government or Others sector.

With respect to the R&D returns I concluded from the literature reviewed that the estimated direct and indirect rates of return present a high dispersion, finding estimations that ranged between 0% and 56% for the direct rate and between 11% to 147% for the indirect rate of return, using similar methodologies and sample data. Also, I found that the empirical estimations focused on the private sector, analyzing groups of firms or technology intensive sectors but not performed on an aggregate level. Because of these limitations and incongruencies I have decided to estimate the rate of return rather than assuming a certain value. I do this by applying a methodology that allows me to estimate a lower-bound for the rate of return as a residual calculation using macroeconomic identity equations with the adjusted national accounts, one setback is that I will not be able to disaggregate direct return and spillovers. As I explained, this is a lower-bound estimate because it does not consider the R&D returns that are already

contained in proprietor's income obtained from investing in other types of capital different from R&D.

From the expenditure and income side definitions of GDP I know that

$$GDP_t = C_t + I_t + G_t + NE_t$$

$$GDP_t = LI_t + PI_t + D_t + IT_t + SD_t = w_t L_t + r_t K_t + \delta K_t + IT_t + SD_t$$

being LI Labour Income, PI Proprietors Income, D Capital Depreciation, IT Income Taxes minus Subsidies, SD Statistical Discrepancy and assuming a geometric depreciation rate δ . As mentioned, I estimated GDP_{Adj} by capitalizing R&D and adjusting the expenditure components, particularly I_{Adj} and G_{Adj} . Adjusting the income side components will imply the following

$$GDP_{Adj,t} = w_t L_{Adj,t} + r_t K_t + \delta K_t + r_t^{RD} K_t^{RD} + \delta^{RD} K_t^{RD} + IT_t + SD_t \quad (2)$$

$$L_{Adj,t} = L_t - L_t^{RD}$$

where $GDP_{Adj,t}$ is obtained adjusting by the expenditure side, w_t is the same wage level in the unadjusted GDP estimation and $L_{Adj,t}$ is the amount of labour after subtracting the human resources involved in R&D activities measured in FTE which are part of the R&D stock of capital. r_t is the rate of return of other kinds of capital different from R&D that, as mentioned, will probably be overestimated as the returns of other kinds of capital contain profits and spillovers obtained from R&D activities; this rate is the same as the one obtained from the unadjusted GDP estimation. On the other hand, K_t , which is the stock of capital different from R&D, is probably an unbiased estimation because R&D resources are mainly devoted to human resources (R&D personnel) and inputs being marginal the acquisition of physical capital (Fraumeni and Okubo 2005). Assuming that both kinds of capital present a geometric depreciation rate and that IT_t and SD_t do not need adjustments, the only unknown variable of equation (2) is r_t^{RD} and so I estimated it as a residual. I must clarify that this methodology did not

appeared in the literature reviewed and I believe is an interesting contribution for estimating a lower-bound R&D rate of return.

In order to estimate how R&D capital accumulation relates with output growth I followed Barro (1999) and performed a growth accounting exercise based on an expanded Cobb-Douglas production function with multiple types of factors. The Cobb Douglas function computed was the following

$$Y_{Adj,t} = A_t L_{Adj,t}^\alpha K_t^\beta K_{RD,t}^\gamma$$

$$\alpha = \frac{w_t L_{Adj,t}}{(Y_{Adj} - \delta K_t - \delta_{RD} K_{RD,t} - IT_t - SD_t)}$$

$$\beta = \frac{r_t K_t}{(Y_{Adj} - \delta K_t - \delta_{RD} K_{RD,t} - IT_t - SD_t)}$$

$$\gamma = \frac{r_{RD,t} K_{RD,t}}{(Y_{Adj} - \delta K_t - \delta_{RD} K_{RD,t} - IT_t - SD_t)}$$

In order to compare the results, I also performed a growth accounting exercise with the standard Solow model not capitalizing R&D which implied not adjusting national accounts.

It is important to bear that the results from the extended growth accounting exercise will also be biased to some extent by the fact that R&D returns are underestimated, reducing the importance of R&D capital accumulation and overestimating the effect of other kinds of capital accumulation over output growth rate. This implies that my results are lower-bound estimates.

5. Results.

My calculations compare Japan's national accounts in which R&D expenditure is considered an investment to those without R&D capital adjustment for the period 1981–2012. I find that on average the real GDP level was 2.9% higher for the adjusted national accounts. Interestingly,

this value is close to the ones estimated for the US and UK R&D capital-adjusted GDP's. My re-estimations of the private investment rate show that it was on average 1.5% higher when including knowledge capital measured by R&D investments. The average output growth rate estimated for the adjusted GDP for the whole period was 1.82% while without R&D capital stock it was 1.78%, a 2% lower. My calculation of Japanese R&D capital stock was on average 7% of the total capital stock (excluding un-produced assets such as land) and it was a relatively constant fraction over the whole period.

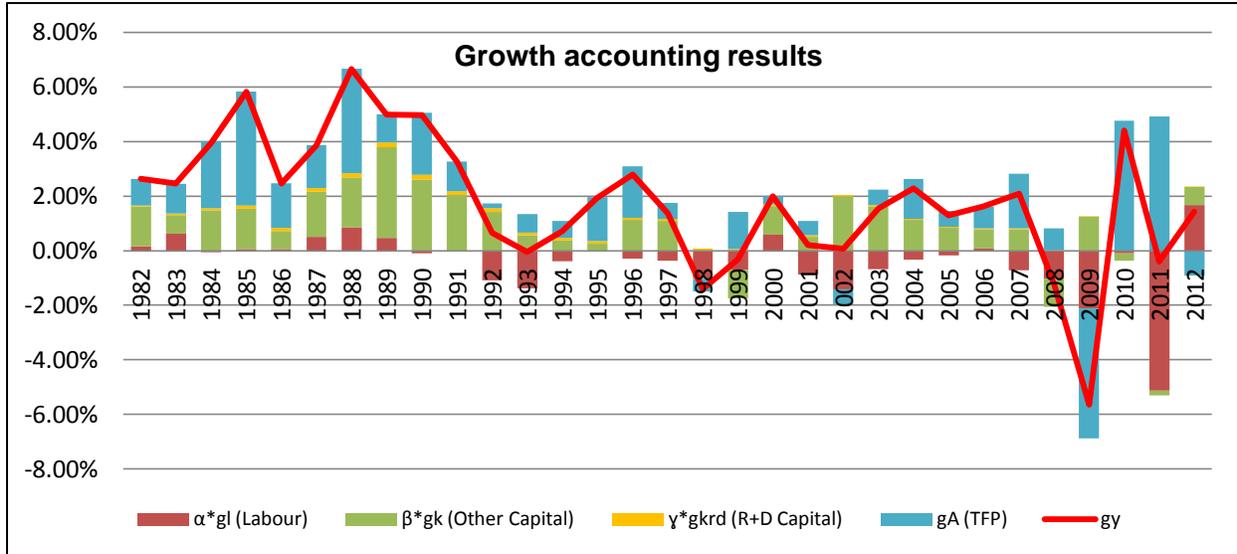
From computing the R&D returns as a residual from the adjusted national accounts I found that the net rate was 7.3%, knowing that this is a lower bound. When I take a closer look to its performance over the period I find that in the 1980's it was 9.8% on average, decreasing to 8.0% in the 90's and to 4.5% in the period between 2001 and 2012.

Interesting to see is that the net rate of return from other types of capital (different from R&D) was 7.9% on average for the whole period, implying that the spread between R&D and other types of investments rate of return was minor. Analyzing the performance of the other types of capital rate of return I also find a decrease from being 11.0% on average in the 1980's, to 7.6% and 5.6% in the 1990's and 2001 onwards, respectively. Looking at Japan's real interest rate published by the International Monetary Fund³, a decrease from 4.9% in the 1980's to 3.1% from 2000 onwards can be seen implying that the reduction in R&D returns was probably related with the output and interest rates reduction which occurred during the 1990's and 2000's when comparing with the 1980's.

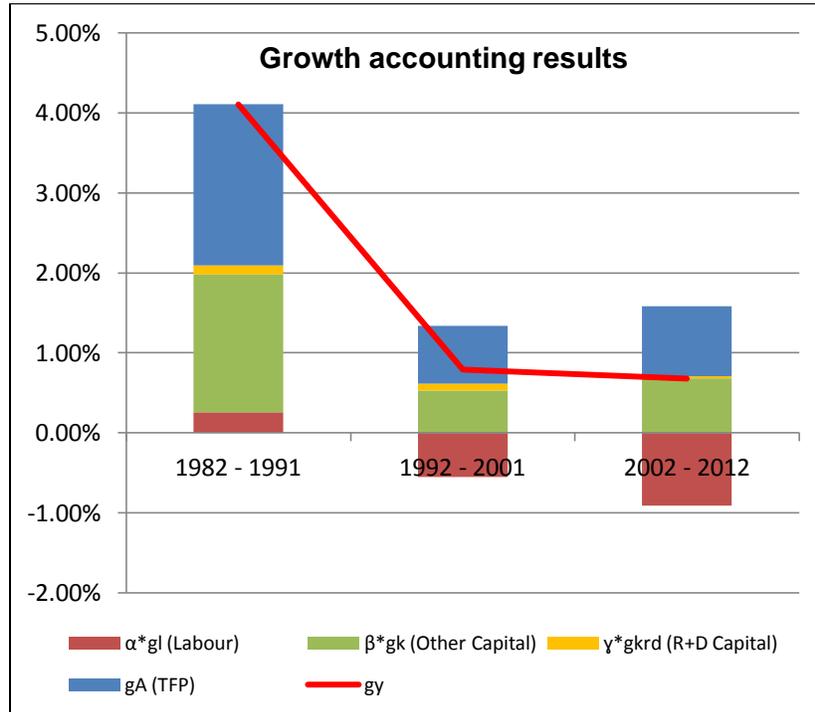
In the final part of the analysis I performed a growth accounting exercise and found that R&D capital accumulation explained close to 3% of output growth rate for the whole period analyzed,

³ Real interest rate is the lending interest rate adjusted for inflation as measured by the GDP deflator published by the International Monetary Fund, International Monetary Statistics.

meanwhile labour accumulation explained more than 16%, physical capital nearly 36% and total factor productivity 45%.



Own elaboration. Data source: MSTI OECD and Japan Statistics Bureau.



Own elaboration. Data source: MSTI OECD and Japan Statistics Bureau.

The relative low importance of R&D accumulation in output growth coincides with Fukao et al. (2009) results after measuring the contribution of intangible assets in Japan's economic growth.

This relative low importance of R&D seems logical considering that R&D capital stock is only 7% of total capital stock and that its returns are probably underestimated. Analyzing how R&D capital accumulation help to explain output growth rate throughout the period I found that in the 1980's it explained nearly 4.5%, decreasing to 3.3% in the 90's and to 1.1% in the period from 2001 to 2012. This decreasing trend can be explain due to the fact that output growth also declined during the period and mainly because labour accumulation reduction, due to a decrease in hours worked per person, explained a higher fraction of output growth rate in the 1990's and 2000's.

I also replicated the growth accounting exercise with the standard data and capital stock, i.e. without R&D capital stock. Thereby I could analyze the change in TFP by including R&D capital stock in national accounts. I find that TFP decreased 3% in its contribution explaining GDP growth. The magnitude of reduction to Abramovitz' 'measure of our ignorance' (Abramovitz 1956) confirms our previous calculations.

6. Robustness checks.

I have performed a number of robustness checks in which I modify some of the principal assumptions considered. The objective of this part of my analysis is to see how my results resist to the feasible extreme values of the parameters proposed in the reviewed literature, but also to establish the range in which my results vary as a result to changes in the parameter assumptions. The most important checks are summarized in Table 1 which also presents the results obtained under the main scenario of this study.

First, I have checked the impact of choosing the manufacturing industry as the sector most proximate to R&D capital stock for deflating. As a check, I changed the deflator used for the GERD series from the Manufacturing Industry Products Index to the implicit GDP deflator and

found that adjusted GDP increased only by 0.1%. This shows that using an overall economy deflator rather than the manufacturing industry product deflator makes a very small difference and that probably any alternative sector deflator would alter my results only very marginally. My results show a low sensitivity to deflator choice.

I also considered a faster depreciation speed by assuming a 25% depreciation rate (the highest rate mentioned in the literature reviewed) and found that the main changes were over the capital stock which reduced its increase from 6.7% to 3.6% and over the R&D net rate of return which increased from 7.3% to 9.9%. The high responsiveness of these results to the rate of depreciation is maintained within a reasonable range. A 127% increase in the depreciation rate reduces the capital stock increase in 54% and increases the rate of return by almost 36%. I think it is safe to assume that the average depreciation rate for R&D capital stock is within a much narrower interval around the 11% rate I have assumed. Assuming an upward or downward bias of the rate of return due to my calibration of the depreciation rate would affect the rate of return to a very limited scope.

Another robustness check performed was by modifying the initial investment considered when estimating the initial capital stock. In my previous calculations I used the 1981–1983 average investment and as a robustness check I substituted with the average of the 1980's decade, which increases the parameter. The main changes in calculations were that the R&D net rate of return decreased to 5.9% and that R&D capital accumulation reduced the fraction of output growth explained from 2.9% (in my previous calculations) to 1.9%. This reveals a very high sensitivity of the final results to the investment we assume for initial capital stock calculation. Nevertheless, it seems more coherent to use the 1981-1983 average which is closer to the initial capital stock to be estimated than the average for the 1980's.

I performed a similar robustness check by changing the investment growth rate considered to estimate the initial R&D capital stock. In my previous calculations I used the average investment

rate over the whole 1981–2012 period and as a check I use the 1980's average investment rate, which derives into a higher investment rate. I found that the R&D net rate of return increases to 8.4% and that R&D capital accumulation increases the fraction of output growth which explains from 2.9% (in the main scenario) to 3.8%. Again I find a high sensitivity to the calibration of the parameter. Nonetheless I prefer the more conservative results I had obtained with the average investment rate.

Last, I analyzed how results changed when modifying various assumptions at the same time. By assuming the higher depreciation rate found in the reviewed literature (25%), a lower initial investment (1981 R&D investment) and a higher investment growth rate (1980's average), all changes that affected R&D rate of return in the same direction ("Upper" scenario), I found that the main change is that R&D net rate of return increased to 10.9% from the original 7.3%. So even if I combine possible biases the magnitude of variation in my results stays within reasonable bounds.

Considering the opposite scenario with the lower depreciation rate found in the literature (7%), a higher initial investment (1980's average) and a lower investment growth rate (1980's average) ("Lower" scenario), the main change is that R&D net rate of return decreased to 5.2% from the original 7.3%.

I could conclude in the case of the rate of return that the results of my robustness checks establish a range of possible upward variation of 50% and a possible downward variation of 28%.

Introducing R&D Capital Stock into National Accounts

Table 1. RESULTS AND ROBUSTNESS CHECKS	Average GDP increase	Average Investment rate increase	Average Capital Increase	Average R+D Net Rate of Return	Average explanation of R+D capital over output growth
	$(GDP_{Adj,t}/GDP_t) - 1$	$(I_{Adj,t}/GDP_{Adj,t}) - (I_t/GDP_t)$	$(K_{RD,t}/K_{Total,t})$		$(\gamma^*g_{KRD,t}) / (\alpha^*g_{L,t} + \beta^*g_{K,t} + \gamma^*g_{KRD,t} + \delta_{TFP,t})$
Main scenario GERD price index deflator: Manufacturing Products Depreciation rate: 11% PIM - Investment in t=1 (in billions of Yens): 3,587 Average 1981 - 1983 PIM - Investment growth rate: 4% Average 1981 - 2012	2.88%	1.53%	6.69%	7.27%	2.88%
Robustness checks					
Changing price deflator scenario GERD price index deflator: GDP Implicit Deflator Depreciation rate: 11% PIM - Investment in t=1 (in billions of Yens): 3,587 Average 1981 - 1983 PIM - Investment growth rate: 4% Average 1981 - 2012	2.97%	1.57%	6.82%	7.38%	2.88%
Faster depreciation scenario GERD price index deflator: Manufacturing Products Depreciation rate: 25% PIM - Investment in t=1 (in billions of Yens): 3,587 Average 1981 - 1983 PIM - Investment growth rate: 4% Average 1981 - 2012	2.88%	1.53%	3.60%	9.88%	1.95%
Higher initial investment scenario GERD price index deflator: Manufacturing Products Depreciation rate: 11% PIM - Investment in t=1 (in billions of Yens): 5,618 Average 1981 - 1990 PIM - Investment growth rate: 4% Average 1981 - 2012	2.88%	1.53%	7.19%	5.86%	1.92%
Higher investment growth rate scenario GERD price index deflator: Manufacturing Products Depreciation rate: 11% PIM - Investment in t=1 (in billions of Yens): 3,587 Average 1981 - 1983 PIM - Investment growth rate: 11% Average 1981 - 1990	2.88%	1.53%	6.39%	8.44%	3.78%
"Upper" scenario GERD price index deflator: Manufacturing Products Depreciation rate: 25% PIM - Investment in t=1 (in billions of Yens): 3,193 1981 PIM - Investment growth rate: 11% Average 1981 - 1990	2.88%	1.53%	3.52%	10.91%	2.50%
"Lower" scenario GERD price index deflator: Manufacturing Products Depreciation rate: 7% PIM - Investment in t=1 (in billions of Yens): 5,618 Average 1981 - 1990 PIM - Investment growth rate: 4% Average 1981 - 2012	2.88%	1.53%	9.68%	5.19%	2.35%

7. Conclusions.

The main motivation that drove this thesis was the idea that knowledge capital has not been correctly tabulated in national accounts affecting our understanding about how knowledge capital relates with other economic variables and growth. Although there is no doubt that economies possess a stock of knowledge which is highly correlated with a country's capacity of generating technological change, resources derived to knowledge activities have been tabulated as expenses, thereby ignoring the existence of knowledge stock.

By estimating the R&D capital stock as a proxy of knowledge capital and adjusting Japan national accounts, I found that the GDP level has been 3% higher on average in the period 1981–2012. I also found that the economy's aggregate capital stock and the private investment rate were 7% and 1.5% higher, respectively.

Because the empirical evidence show great dispersion when estimating R&D returns, I decided to estimate Japan's R&D rate of return from an aggregate approach instead of assuming a given value. Using a methodology I developed, I estimated a lower bound of the R&D net rate of return as a residual from macroeconomic identity equations and found that it was 7.3% on average. I also estimated the rate of return of other types of capital different from R&D and found it was 7.9% evidencing, that -if my calculations are correct- in an advanced economy such as Japan, capital movement is not constrained and this reduces the spread of different capital returns. Moreover, finding a R&D rate of return similar to the economy's aggregate rate of return confirms the robustness of the methodology developed, making attractive to apply it over other countries in future research.

From performing a growth accounting exercise with multiple types of capital I found that R&D capital accumulation explained on average 3% of output growth, comparing to labour accumulation (16%), other types of capital (36%) and TFP growth (45%). This lower effect over

output growth can be explain by the fact that R&D capital is only 7% of total capital stock and that R&D returns are probably underestimated.

Analyzing how R&D capital accumulation helps to explain the output growth rate throughout the period I found that in the 1980's it explained nearly 4.5%, decreasing to 3.3% in the 1990's and to 1.1% in the period from 2001 to 2012. This decreasing importance seems coherent when considering that output growth decreased during the 1990's and 2000's comparing with the 1980's and labour accumulation explained a larger share of output growth.

I performed robustness checks modifying the main assumptions, such as the depreciation rate considered, the index price deflator used and the parameters selected for estimating the initial R&D capital stock, and in all cases I found that results estimated are robust.

The main conclusion of this work is that in order to increase our understanding of how knowledge capital relates with economic growth and improve the accuracy of national accounts it is mandatory to capitalize R&D resources and this thesis is a contribution in that sense.

I may add that, comparing these results with the ones obtained by the US and UK statistics authorities after including R&D capital stock into their national accounts, similarities can be seen, evidencing common patterns among advanced countries, patterns interesting to analyze in future research.

Moreover, the level of the results obtained confirm the importance of estimating and including R&D capital stock into national accounts, effort that some advanced countries have already embraced and which developing countries also should start considering. Although it can be assumed that knowledge capital is less relevant in developing economies, without standardized data and accepted estimation methodologies, we will not be able to confirm or reject this assumption.

8. References.

- Abramovitz, M. (1956). Resource and output trends in the United States since 1870. In *Resource and Output Trends in the United States Since 1870* (pp. 1-23). NBER.
- Abramsky, J. (2014). *Changes to National Accounts: Framework for Research and Development in the United Kingdom National Accounts*. United Kingdom's Office for National Statistics.
- Aghion, P. and Howitt, P. (2009). *The Economics of Growth*. The MIT Press.
- Barro, R. J. (1999). Notes on growth accounting. *Journal of Economic Growth*, 4(2), 119-137.
- BEA (2014). *Concepts and methods of the US National Income and Product Accounts*. BEA.
- Berlemann, M., & Wesselhöft, J. E. (2014). Estimating Aggregate Capital Stocks Using the Perpetual Inventory Method. *Review of Economics*, 65. Jg., 1-34.
- Bresnahan, T. F., & Trajtenberg, M. (1995). General purpose technologies 'Engines of growth'?. *Journal of econometrics*, 65(1), 83-108.
- CBO, U. (2005). *R&D and Productivity Growth: A Background Paper*. The Congress of the United States, Congressional Budget Office.
- Conesa, J. C., Kehoe, T. J., & Ruhl, K. J. (2007). Modeling great depressions: the depression in Finland in the 1990s (No. w13591). NBER.
- De la Fuente, A. and Domenech, R. (2000). Human Capital in Growth Regressions: How Much Difference Does Data Quality Make? Economics Department Working Paper, 262, OECD, Paris.
- Diaz, A. and Franjo, L. (2014). Capital goods, measured TFP and growth: the case of Spain. Universidad Carlos III de Madrid. Department of Economics. Working Paper Economics 14-22.
- Dougherty, S. M., R. Inklaar, R. H. McGuckin, and B. Van Ark. 2004. Internationally comparable science, technology, and competitiveness indicators. Report to the National Science Foundation. New York: The Conference Board.
- Fraumeni, B. M., & Okubo, S. (2005). R&D in the national income and product accounts: A first look at its effect on GDP. In *Measuring capital in the new economy* (pp. 275-322). University of Chicago Press.
- Fukao, K., Miyagawa, T., Mukai, K. and Shinoda, Y. (2009). Intangible Investment in Japan: Measurement and Economic Contribution to Economic Growth. *Review of Income and Wealth*. Series 55, Number 3.

- Goto, A., & Suzuki, K. (1989). R & D capital, rate of return on R & D investment and spillover of R & D in Japanese manufacturing industries. *The Review of Economics and Statistics*, 555-564.
- Griliches, Z. (1979). Issues in assessing the contribution of research and development to productivity growth. *The Bell Journal of Economics*, 92-116.
- (1957). Hybrid corn: An exploration in the economics of technological change. *Econometrica, Journal of the Econometric Society*, 501-522.
- (1984). R&D, patents, and productivity. Cambridge, MA: University of Chicago Press.
- Guellec, D. and van Pottelsberghe de la Potterie, B. (2001). R&D and productivity growth: panel data analysis of 16 OECD countries. International Monetary Fund Working Papers.
- Harberger, A. C. (1978): Perspectives on Capital and Technology in Less Developed Countries. In: M. J. Artis and A. R. Nobay (Eds.): Contemporary Economic Analysis, London, 42–72.
- Holtz-Eakin, D. (2005). R&D and productivity growth: a background paper. Congressional Budget Office.
- Huang, N. (2007). Measuring the stock of the aggregate R&D capital in the growth accounting framework. University of British Columbia.
- Jaffe, A. B. (1986). Technological opportunity and spillovers of R&D: evidence from firms' patents, profits and market value (No. w1815). NBER.
- (1973). A price index for deflation of academic R&D expenditures. NSF Working Paper no. 72-310. Washington, DC: National Science Foundation.
- Japan Statistical Yearbook 2015 (2015). Statistics Bureau, Ministry of Internal Affairs and Communications.
- Ker, D. (2014). Changes to National Accounts: Measuring and Capitalising Research and Development. United Kingdom's Office for National Statistics.
- Lee, J. and Schmidt, A. (2010). Research and Development Satellite Account. BEA.
- Li, W. C. (2012). Depreciation of business R&D capital. U.S. Bureau of Economic Analysis.
- Main Science and Technology Indicators (2015). MSTI Volume 2014/2. OECD.
- Nadiri, M. I. (1993). Innovations and technological spillovers (No. w4423). NBER.
- Office for National Statistics (2014). The Blue Book 2014 Edition. United Kingdom's Office for National Statistics.
- OECD, Frascati Manual. (2002). Proposed Standard Practice for Surveys on Research and Experimental Development. The Measurement of Scientific and Technological Activities Series. Paris. OECD.

- Olmstead, A. L., & Rhode, P. (1993). Induced innovation in American agriculture: A reconsideration. *Journal of Political Economy*, 100-118.
- Prados de la Escosura, Leandro (2014). Mismeasuring long run growth: the bias from spliced national accounts. Universidad Carlos III de Madrid. Instituto Figuerola de Historia y Ciencias Sociales. Working Paper in Economic History 14-04.
- Sliker, B. (2007). 2007 R&D Satellite Account Methodologies: R&D Capital Stocks and Net Rates of Return. R&d satellite account background paper, BEA/National Science Foundation.
- Solow, R. M. (1957). Technical change and the aggregate production function. *The review of Economics and Statistics*, 312-320.
- System of National Accounts 2008 (2009). European Communities, International Monetary Fund, Organization for Economic Co-operation and Development, United Nations and World Bank.
- Sveikauskas, L. (2007). R&D and productivity growth: a review of the literature. U.S. Bureau of Labor Statistics.
- Ulku, H. (2004). R&D, innovation, and economic growth: An empirical analysis. International Monetary Fund.