Total Factor Productivity Growth and the Environment: A Case for Green Growth Accounting

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Abstract

Growth Accounting allows for the breakdown of output growth into components and estimates the contribution of each component in the final output growth. Following Solow's tradition, which interprets the "residual" as a source of growth associated with technological change, we examine whether the use of the environment, in the form of CO_2 emissions as an input in production contributes, in addition to conventional factors of production, to output growth and should be accounted for in total factor productivity (TFPG) measurement.

A theoretical framework of growth accounting methodology with environment as a factor of production which is unpaid in the absence of environmental policy is developed. Using data from a panel of 23 OECD countries, we show that emissions' growth have a statistically significant contribution to the growth of output per worker and emission augmenting technical change is present along with labor augmenting technical change. Our results suggest that this approach can contribute in developing a concept of "*Green Growth Accounting*".

JEL Classification: O47, Q2

Key Words: Solow Residual, Total Factor Productivity Growth, Growth, Environment, Green Growth Accounting.

1 Introduction

Growth Accounting is the empirical methodology that allows for the breakdown of output growth into its components and estimates the contribution of each component in the final output growth. The concept of total factor productivity

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growth (TFPG), which is central in growth accounting and the idea that apart from labor other factors such as land and capital also contribute in the growth of the final output, was firstly discussed in the early 1930's[1]. Growth accounting still remains a central concept in growth theory, however even recently there are still conceptual disputes about the subject and Easterly and Levine (2001) state that "economists need to provide much more shape and substance to the amorphous term TFP". In this paper we try to provide some additional "shape" by considering the use of environment as a source of growth.

Solow in the late 1950's, (Solow, 1957) put the foundations of the growth accounting methodology, which imply decomposing of total output growth and measuring the contribution of all specific factors to growth, including that of technological progress. During the last decades, many different approaches were used to measure TFPG, including dual approaches using factor prices instead of factor quantities, and introduction into the growth accounting framework of factors such as: externalities; knowledge; taxation; multiple inputs; R&D;intermediate inputs and quality ladders; adaptation of new technologies, responses to the importance of technological change.[2]

In the early 1970's, starting with William Brock and his article "A Polluted Golden Age" (1973), a new dimension was given to the theory of economic growth with the introduction of *environmental damages* created by emissions into aggregate growth models. This new dimension that generated a large volume of literature on "Growth and the Environment"[3] is an important viewpoint for growth accounting since it implies a new way of looking at TFPG measurement. Brock stated that "received growth theory is biased because it neglects to take into account the pollution costs of economic growth", introduced emissions as an input in the production function and environmental damages into the utility function, and analyzed the impact of the environment on economic growth in the context of an optimal growth model. In an unregulated market, the cost of pollution cannot be easily measured and pollution could be an unpaid factor, thus production is more costly if less pollution is allowed. Brock (1973) by introducing emissions as an input in the production function, regards environment as a factor of production and not just as a by-product of the production process. The idea here is that the use of the environment in the production process is captured by introducing emissions as an input in an aggregate production function.[4]

Following this methodological approach, the idea developed in this paper is that when emissions are introduced as an input in the production process and are properly measured, then the contribution of environmental pollution in

[1] See for example, Griliches (1996).

[2] See for example Jorgenson and Griliches (1967, 1979), Aghion and Howitt (1992, 1998), Grossman and Helpman (1991), Easterly and Levine (2001), Parente and Prescott (1996). Recent studies in TFP growth measurement in the micro level, decompose TFP into a scale effect an efficiency change effect and a technological change effect, for example Lansink, Silva and Stefanou (2000).

[3] See for example Aghion and Howitt (1998) or surveys such as: Brock and Taylor (2005), Xepapadeas (2005).

[4] In this context, the production function has been specified to include the flow of pollution as an input and, some times, productivity enhancing environmental quality as a stock variable. This formulation has been used frequently in the theoretical analyses of growth and the environment. In addition to Brock (1973), see for example, Becker (1981), Tahvonen and .Kuluvainen (1993), Bovenberg and Smulders (1995), Smulders and Gradus (1996), Mohtadi (1996), Xepapadeas (2005), Brock and Taylor (2005).

total output growth can also be measured. We assume that environment is an unpaid input in the production process, in the absence of environmental policy, and it is used basically as a place of depositing the emissions created by the production process. This could provide a new way of looking at the growth accounting methodology, because this unpaid factor of production – the environment - contributes in total output growth by providing the natural resources and the "place" where the negative externalities of the production process are placed. Thus our analysis treats emissions as an input in the production function, which may be used without direct costs, due to the absence of appropriate environmental policy. In this sense, emissions can determine, along with other inputs and technological progress output growth in a growth accounting framework. Therefore, the present paper can be regarded as an attempt to explore systematically whether the use of the environment as an input in production contributes to output growth, and how this contribution can be measured.[5]

We develop a growth accounting framework for measuring TFP growth by taking environmental pollution - in the form of carbon dioxide (CO_2) emissions - into account[6]. We expect that this approach might influence the current TFP growth estimation approaches due to the introduction of a potentially significant factor of production which is basically unpaid in real world - the environment. Our purpose is to examine the contribution of emissions' growth, as a proxy for the use of environment, on economic growth and to show that, since external pollution costs which are created during the production process are not taken into account in the measurement of total factor productivity growth, the current measurements of TFP growth or the Solow "residual", could provide biased results. Our basic hypothesis, which has been tested empirically, is that emissions, in the form of CO_2 emissions is an *unpaid* source of output growth and thus the use of environment might explain part of output growth. Furthermore, if emissions saving technical change is present this could be another source of growth in addition to the conventional labor augmented technical change. This hypothesis is assessed and tested empirically in this paper by using data from a panel of 23 OECD countries.

Our theoretical and empirical analysis seems to suggest that the "unpaid" environmental factor in the form of input of CO_2 emissions - due to absence of taxation - could be a significant source of growth, and an important component in the growth accounting methodology, supporting the case of a "Green Growth Accounting" approach. We feel that this type of analysis could be important, because if the use of the environment is a source of growth, as our results seem to suggest, but environment is used as an unpaid factor, environmental damages remain "unpaid". By being "unpaid" however, they are not kept at a "socially optimal level" during the growth process and this fact might eventually erode the sustainability of the growth process itself.

The paper is structured as follows. Section 2, is a descriptive section that provides some stylized facts related to the evolution of emissions per worker and

[5]It is important to note that the approach we choose to follow is an aggregate macroeconomic approach that belongs to the Solow tradition of measuring TFP growth from a macroeconomic perspective. This is not the same as TFPG measurement at the micro-level where TFPG is usually measured with the use of distance functions and linear programming approaches. (See for instance, Pitman (1983), Fare, et all, (1989, 1993).

[6]Strictly speaking CO_2 emissions is not a pollutant but we treat them as such because of their close relation to climate change and the implied environmental damages.

output per worker and the relation between emission growth and output growth in per worker terms. Section 3 develops the growth accounting framework and interprets emissions' share in output in the context of optimal growth and competitive equilibrium. Since in general we don't have taxation for the emissions of CO_2 and therefore the share of emission taxes are not included in National Accounts, estimating TFPG, as it is the most common approach, using data on input shares in output, might provide biased estimates since the share of emission damages is ignored. We try to solve this problem at the empirical level by equating the emission's share in total output with the share of environmental damages in total output, using independent estimates for CO_2 damages or by estimating directly the emission's share from an aggregate production function where CO_2 emissions is an input along with labor and capital. Thus, section 4, develops two approaches for measuring a 'green' TFPG. The first, is a direct approach for adjusting existing TFPG measurements, using estimates for CO_2 damages, while the second provides estimates for a "green" TFP, based on econometric estimation of growth accounting equations and production functions, and a decomposition of technical change to labor and emission augmenting. Section 5, provides the actual measurements which suggest that the use of the environment seems to be a statistically significant factor in explaining output growth. This can be interpreted as an indication that the TFPG measurements that do not take the environmental factor into account might be biased. Our results indicate furthermore, that labor augmenting technological progress, is not the only factor that constitutes the "residual" but "emission augmenting technical change" might also be present. The last section concludes.

2 CO_2 Emissions and Output: Some Descriptive Results

This is a descriptive section which tries to provide some stylized facts regarding a possible link between the growth of CO_2 emissions and final output growth for a group of 23 OECD economies.[7], [8].

Figure 1, shows gross domestic product (GDP) in per worker terms (GDP/W) for a group of 22 OECD countries[9], compared to the GDP/W when $USA = 1$[10]. The years we compare are 1965 and 1990 and the conclusion we come to, is that the countries analyzed managed to reduce the growth "distance" from USA in GDP per worker terms and increased their GDP/W from 1965 to 1990, both in absolute terms and relative to the USA.

Figure 1

Figure 2 that follows, shows emissions of CO_2 per worker (CO_2/W) for the

[7] The 23 countries used in our analysis are the following: Canada, U.S.A, Austria, Belgium, Denmark, Finland, France, Greece, Italy, Portugal, Spain, Sweden, Switzerland, U.K., Japan, Iceland, Ireland, Netherlands, Norway, Australia, Mexico, Turkey, Luxembourg.

[8] Our data are taken from the Penn Tables v5.6. Real GDP measured in thousands of US$ is the variable (RGDPCH), multiplied by the variable POP in the Penn Tables. Capital stock and employment are retrieved from Real GDP and capital per worker (KAPW) and real GDP per worker (RGDPW). All values are measured in 1985 international prices. CO_2 data are taken from the World Bank and are measured in thousand tons of CO_2 emissions.

[9] Luxembourg, has been excluded for presentation purposes.

[10] USA is used as a benchmark country for obvious reasons.

years 1965 and 1990 respectively. We compare the group of the 22 countries by taking USA as the benchmark country again (USA=1). It can be noticed that in some countries (6 out of 22),[11] CO_2/W was reduced during these years, while for the rest (16 out of 22), CO_2 emissions per worker increased.

Figure 2

Figure 3, represents CO_2 emissions per unit of GDP (CO_2/GDP) for the years 1965 and 1990. USA is taken as the benchmark country again and the comparisons show that for the majority of countries CO_2 (15 out of 22) emissions per unit of GDP increased whereas in the rest (7 out of 22) emissions per unit of GDP decreased.[12]

Figure 3

Figure 4, represents on the vertical axis the average *growth of* GDP per worker and in the horizontal axis the *growth of* CO_2 per worker between 1965 and 1990. Each point of the scatter diagram represents one of the 23 countries we analyze. There is on the average a positive relationship between the two variables, suggesting that countries with high growth of CO_2 per worker can be associated with a high growth of GDP per worker. This can be regarded as an indication that the growth of CO_2 per worker contributes to the growth of GDP per worker

figure 4

Figure 5, shows on the horizontal axis GDP per worker relative to the GDP per worker in USA at 1965, and on the vertical axis is the average growth of CO_2 per worker for the examined period. Countries with GDP per worker close to the USA GDP per worker. in 1965 (which equals to 1) had relatively low growth rates of CO_2 per worker. On the other hand, countries that were "far away" (below) in GDP per worker relative to the USA in 1965, presented a relatively high rate of growth of CO_2 per worker. An attempt to explain this would be to say that countries with low GDP per worker. in 1965 relatively to the USA, were developing relatively fast and during their development processes emitted relatively more carbon dioxide, probably due to the use of "dirtier" technologies and not sufficiently strong emissions augmented technical change.

figure 5

The last three figures (6,7,8) depict the evolution of GDP/W and CO_2/W for the years 1965-1990 for USA, Italy and Japan respectively. These figures represent two typical patterns. While output per worker is upward sloping, emissions per worker in the USA, seem to have an inverted U shape with a turning point in mid-seventies, while in Italy and Japan an inverted U shape cannot be detected, but again around mid-seventies there is a slowdown in emissions per worker, which is more profound in Japan's case. This seems to suggest in combination with the results of figures 2 and 3 that although emissions were not taxed during the period under examination, there is a reduction in some countries in emissions per worker and per GDP terms. This might be explained

[11] The countries are: Belgium, Denmark, France, Sweden, UK and Iceland.

[12] These are the same countries as those for which CO_2/W reduced between 1965 and 1990 with the addition of Canada.

by emission savings technical change induced by responses to energy prices, or to introduction of general environmental policies, which although not directed at CO_2 emissions might have introduced technological or capacity constraints which eventually affected CO_2 emissions.

$$figures\ 6,\ 7,\ 8$$

The descriptive data, provide us with some indications that the growth of CO_2 emissions per worker seem to be positively related to the growth of output per worker and that some kind of emission savings technical change might be present. This could imply that the use of the environment is a factor that influences the output growth of an economy, and as such it should be taken into account into growth accounting calculations.

In the following we are trying to develop a theoretical and empirical framework for testing this hypothesis which, provides a "green" perspective to the framework of the TFPG measurement.

3 Primal Growth Accounting with Environmental Considerations

In this we derive the traditional Solow's residual under environmental considerations. For this reason, we augment, as described in the introduction, the aggregate neoclassical production function used in standard growth accounting exercises with emissions as an input. Let,

$$Y = F(K, E) = F(K, AL) \tag{1}$$

where Y is aggregate output, K is physical capital, $E = AL$ is effective labour, with L being labour input and A reflecting labour augmenting (Harrod neutral) technical change. The 'Solow residual' is defined as (e.g. Romer 1999, Barro and Sala-i-Martin 2004)

$$g_S = s_L \left(\frac{\dot{A}}{A} \right) = \frac{\dot{Y}}{Y} - s_K \left(\frac{\dot{K}}{K} \right) - s_L \left(\frac{\dot{L}}{L} \right) \tag{2}$$

where s_K and s_L are the shares of capital and labor in output, with two factors receiving their competitive rewards. Under constant returns of scale, $s_L + s_K = 1$, and we have:

$$g_S = s_L \left(\frac{\dot{A}}{A} \right) = \frac{\dot{y}}{y} - s_K \frac{\dot{k}}{k} \tag{3}$$

where $\dot{y}/y$ is the rate of growth of per worker output ($y = Y/L$) and $\dot{k}/k$ is the rate of growth of per worker capital ($k = K/L$)[13]. If x denotes the rate of the exogenous labor augmenting technical change, then:

$$x = \frac{\dot{A}}{A} = \frac{1}{1 - s_K} \left(\frac{\dot{y}}{y} - s_K \frac{\dot{k}}{k} \right) \tag{4}$$

[13] As is the convention in this literature lower case letter denotes per worker quantities.

By following ideas appeared in Denison (1962), Dasgupta and Maler (2000), Xepapadeas (2005) which relate environment to growth accounting, we define a standard neoclassical production function that includes human capital and emissions as an input of production and we use it to determine a growth accounting equation. Let

$$Y = F(K, H, E, X) \tag{5}$$

where K is physical capital and $E = AL$ is effective labour as before, H is human capital, $X = BZ$ is effective input of emissions, with Z being emissions in physical units and B reflecting emission saving technical change, or input augmenting technical change.

Differentiating (5) with respect to time, and denoting by $\epsilon_j, j = K, H, L, Z$ the elasticity of output with respect to inputs, the basic growth accounting equation is obtained as:

$$\frac{\dot{Y}}{Y} = \epsilon_K \left(\frac{\dot{K}}{K}\right) + \epsilon_H \left(\frac{\dot{H}}{H}\right) + \epsilon_L \left(\frac{\dot{A}}{A}\right) + \epsilon_L \left(\frac{\dot{L}}{L}\right) + \epsilon_Z \left(\frac{\dot{B}}{B}\right) + \epsilon_Z \left(\frac{\dot{Z}}{Z}\right) \tag{6}$$

Equation (6) says that the growth rate of GDP can be decomposed into the growth rate of four components, manufactured capital, human capital, physical labor and emissions in physical units. To transform equation (6) into a growth accounting equation in factors shares, we use, as before, profit maximization in a competitive market set up. We assume that physical and human capital receive there rental rates R_K and R_H, labor receives wage w and emission are taxed at a rate $\tau \geq 0$, since they create external damages. Thus, profits for the representative firm are defined as:

$$\Pi = F(K, H, E, X) - R_K K - R_H H - wL - \tau Z \tag{7}$$

with associated first-order conditions for profit maximization:

$$\frac{\partial F}{\partial K} = R_K \ , \ \frac{\partial F}{\partial H} = R_H \tag{8}$$

$$\frac{\partial F}{\partial E} A = \frac{\partial F}{\partial L} = w \tag{9}$$

$$\frac{\partial F}{\partial X} B = \frac{\partial F}{\partial Z} = \tau \tag{10}$$

Denoting by $s_j, j = K, H, L, Z$ the factors' shares in total output, then under profit maximization the basic growth accounting equation is obtained as:

$$\frac{\dot{Y}}{Y} = s_K \left(\frac{\dot{K}}{K}\right) + s_H \left(\frac{\dot{H}}{H}\right) + s_L \left(\frac{\dot{A}}{A}\right) + s_L \left(\frac{\dot{L}}{L}\right) + s_Z \left(\frac{\dot{B}}{B}\right) + s_Z \left(\frac{\dot{Z}}{Z}\right) \tag{11}$$

where:

$$s_K = \frac{R_K K}{Y}, s_H = \frac{R_H H}{Y}, s_L = \frac{wL}{Y}, s_Z = \frac{\tau Z}{Y} \tag{12}$$

If we assume that investment in physical and human capital is carried out up to the point where marginal products in each type of capital (physical and human capital) are equated in equilibrium,[14] (see for example Barro and Sala-i-Martin

[14] This assumption has been used to justify relatively high estimates of capital's share in empirical growth equations.

2004), we have:

$$H = \frac{s_H}{s_K} K \tag{13}$$

Substituting (13) into (11) we obtain:

$$\frac{\dot{Y}}{Y} = s_{KH}\left(\frac{\dot{K}}{K}\right) + s_L\left(\frac{\dot{A}}{A}\right) + s_L\left(\frac{\dot{L}}{L}\right) + s_Z\left(\frac{\dot{B}}{B}\right) + s_Z\left(\frac{\dot{Z}}{Z}\right) \tag{14}$$

$$s_{KH} = s_K + s_H \tag{15}$$

Thus, the Solow residual augmented with human capital and emissions can be defined in the following two ways:

$$\gamma = s_L\left(\frac{\dot{A}}{A}\right) + s_Z\left(\frac{\dot{B}}{B}\right) = \frac{\dot{Y}}{Y} - s_K\left(\frac{\dot{K}}{K}\right) - s_H\left(\frac{\dot{H}}{H}\right) - s_L\left(\frac{\dot{L}}{L}\right) - s_Z\left(\frac{\dot{Z}}{Z}\right) \tag{16}$$

or by using the assumption of equality of marginal products between physical and human capital, we have:

$$\gamma = s_L\left(\frac{\dot{A}}{A}\right) + s_Z\left(\frac{\dot{B}}{B}\right) = \frac{\dot{Y}}{Y} - s_{KH}\left(\frac{\dot{K}}{K}\right) - s_L\left(\frac{\dot{L}}{L}\right) - s_Z\left(\frac{\dot{Z}}{Z}\right) \tag{17}$$

Equations (16) or (17) can be used to define and estimate total factor productivity growth (TFPG) and the *Solow residual*, in the case where the production function includes emissions and human capital as a factor of production.[15] Since one of the major long term environmental issues is global warming and climate change, and since there are strong indications of a link between global warming and Carbon Dioxide emissions, we can interpret the input "emissions" as CO_2 emissions. Under constant returns to scale (16) and (17) become:

$$\frac{\dot{y}}{y} = \gamma + s_K\frac{\dot{k}}{k} + s_H\frac{\dot{h}}{h} + s_Z\frac{\dot{z}}{z} \tag{18}$$

$$\frac{\dot{y}}{y} = \gamma + (s_K + s_H)\frac{\dot{k}}{k} + s_Z\frac{\dot{z}}{z} \tag{19}$$

By comparing the new definitions for TFPG, (16) or (17) with (3), it can be seen that the TFPG's defined in (17) and (16) include the term $s_Z\left(\dot{B}/B\right)$ associated with emission augmenting technical change in addition to the standard labour augmenting technical change. The term $s_Z\left(\dot{Z}/Z\right)$ indicates that there is one more source generating output growth in addition to capital and labour, namely emissions. The inclusion of emissions reflect the fact that the environment contributes to output growth and in order to obtain a "net" estimate for TFPG the environment's contribution should be properly accounted. In the context of our analysis (17) or (16) can be regarded as the *Green Growth Accounting equations.* In order however to provide a meaningful definition of the TFPG

[15] In the conventional formulation for the estimation of TFP growth the definition of the production function does not include emissions so that $s_Z \equiv 0$ and TFP growth is defined as in (**??**) with the possible addition of the term associated with human capital.

when emissions is an input, there is a need to clarify what is meant by the share of emissions in output, especially since when it comes to empirical estimations there might be data sets where $\tau = 0$, that is emissions are untaxed and we have one unpaid input in the production function.

3.1 Interpreting the Emissions' Share in Growth Accounting

3.1.1 The Social Planner

To interpret the emissions share even when no environmental taxation is present ($\tau = 0$),we consider the problem of a social planner seeking to optimize a felicity functional defined over consumption and environmental damages and to determine an optimal emission tax, optimal in the sense that if firms pay this tax on their emissions they will emit the socially desirable levels of emissions. An optimal tax would internalize the externalities that the emissions create during the production process.

We assume that emissions (flow variable), accumulate into the ambient environment and that the evolution of the emission stock S, is described by the first order differential equation:

$$\dot{S}(t) = Z(t) - mS(t) \;,\; S(0) = S_0, m > 0 \tag{20}$$

where m reflects the environment's self cleaning capacity[16]. The stock of emissions generate damages according to a strictly increasing and convex damage function $D(S)\,,\, D^{'} > 0, D^{''} \geq 0$.

Assume that utility for the "average person" is defined with a separable function $U(c(t), S(t))$ where $c(t)$ is consumption per capita, $c(t) = C(t)/N(t)$, with $N(t)$ being population. We assume as usual that $U_c(c,S) > 0$, $U_S(c,S) < 0$ $U_{cS}(c,S) \leq 0$, that U is concave in c for fixed S, and finally that U is homogeneous in (c,S). Then social utility at time t is defined as $N(t)U(c(t), S(t)) = N_0 e^{nt} U(c(t), S(t))$ where n is the exogenous population growth rate and N_0 can be normalized to one. The objective for the social planner is to choose consumption and emission paths to maximize:

$$\max_{\{c(t),Z(t)\}} \int_0^{\infty} e^{-(\rho-n)t} U(c,S)\,dt \tag{21}$$

where, $\rho > 0$ is the rate of time preference, subject to the dynamics of the capital stock and the pollution stock (20). The capital stock dynamics can be described in the following way. Assume a constant returns to scale Cobb-Douglas specification for the production function (5):

$$Y = K^{a_1} H^{a_2} (AL)^{a_3} (BZ)^{a_4}$$

[16]We use a very simple pollution accumulation process which has been often used to model global warming. The inclusion of environmental feedbacks and nonlinearities which represent more realistic situations will not change the basic results.

where: $a_1 + a_2 + a_3 + a_4 = 1$. Expressing output in per worker terms we obtain:

$$\begin{aligned}
\frac{Y}{L} &= \left(\frac{K}{L}\right)^{a_1}\left(\frac{H}{L}\right)^{a_2}\left(\frac{AL}{L}\right)^{a_3}\left(\frac{BZ}{L}\right)^{a_4} \\
\frac{Y}{L} &= y = k^{a_1}h^{a_2}(e^{xt})^{a_3}(e^{(b-n)t}Z)^{a_4}, \text{ or} \\
y &= e^{\zeta t}k^{a_1}h^{a_2}Z^{a_4}, \ \zeta = xa_3 + a_4(b-n)
\end{aligned}$$

Labor augmenting technical change grows at the constant rate x, input (emission) augmenting technical change grows at a constant rate b, labor grows at the population rate n,and as usual $y = \frac{Y}{L}, k = \frac{K}{L}, c = \frac{C}{L}$and $h = \frac{H}{L}$, are expressed in per capita (or per unit of worker) terms. Assuming equality of depreciation rates and equality of marginal products between manufactured and human capital in equilibrium the social planner's problem can be written as:[17]

$$\max_{\{\hat{c}(t),Z(t)\}} \int_0^\infty e^{-\omega t}U(\hat{c},S)\,dt \ , \omega = \rho - n - (1-\theta)\xi \tag{22}$$

subject to: (23)

$$\dot{\hat{k}} = f\left(\hat{k},Z\right) - \hat{c} - (\eta+\delta+\xi)\hat{k}, \quad f\left(\hat{k},Z\right) = s\tilde{A}\hat{k}^{\beta}Z^{a_4} \tag{24}$$

$$\dot{S} = Z - mS \tag{25}$$

The current value Hamiltonian for this problem is:

$$\mathcal{H} = U(\hat{c},S) + p\left[f\left(\hat{k},Z\right) - \hat{c} - (\eta+\delta+\xi)\hat{k}\right] + \lambda(Z - mS) \tag{26}$$

the optimality conditions implied by the maximum principle are:

$$\begin{aligned}
U_{\hat{c}}(\hat{c},S) &= p \ , \ U_{\hat{c}\hat{c}}(\hat{c},S)\dot{\hat{c}} = \dot{p} &(27)\\
pf_Z\left(\hat{k},Z\right) &= -\lambda \ or \ Z = g\left(\hat{k},\lambda,p\right) &(28)\\
\dot{p} &= \left(\rho+\delta+\theta\xi - f_{\hat{k}}\left(\hat{k},Z\right)\right)p \text{ or} &(29)\\
\frac{\dot{\hat{c}}}{\hat{c}} &= \frac{1}{\theta}\left[f_{\hat{k}}\left(\hat{k},g\left(\hat{k},\lambda,U_{\hat{c}}(\hat{c},S)\right)\right) - \rho - \delta - \xi\theta\right] &(30)\\
\dot{\lambda} &= (\omega+m)\lambda - U_S(\hat{c},S) &(31)
\end{aligned}$$

The system of (30), (31) along with the two differential equation below:

$$\begin{aligned}
\dot{\hat{k}} &= f\left(\hat{k},g\left(\hat{k},\lambda,U_{\hat{c}}(\hat{c},S)\right)\right) - \hat{c} - (\eta+\delta+\xi)\hat{k} &(32)\\
\dot{S} &= g\left(\hat{k},\lambda\right) - mS &(33)
\end{aligned}$$

form a dynamic system, which along with the appropriate transversality conditions at infinity (Arrow and Kurz 1970) characterizes the socially optimal paths of $\left(\hat{c},\hat{k},\lambda,S,Z\right)$.

[17] For the derivation see Appendix.

Let the value function of the problem be defined as

$$J\left(K_0, S_0\right) = \max \int_0^{\infty} e^{-\omega t} U\left(\hat{c}, S\right) dt \tag{34}$$

then it holds that (Arrow and Kurz 1970):

$$\frac{\partial J}{\partial S\left(t\right)} = \lambda\left(t\right) < 0 \tag{35}$$

Thus the costate variable λ can be interpreted as the shadow cost of the pollution stock. By comparing (35) with (10) it is clear that if a time dependent tax $\tau\left(t\right) = -\lambda\left(t\right)/p\left(t\right)$ is chosen, then firms will choose the socially optimal amount of emissions as input.

Then the emission's share can be written as:

$$s_Z = \frac{\tau Z}{Y} = \frac{\left(-\hat{\lambda}\right) Z}{Y}, \ \hat{\lambda} = \frac{-\lambda}{p} = \frac{-\lambda}{U_{\hat{c}}} \tag{36}$$

where from (36) $\hat{\lambda}$ can be interpreted as the shadow cost of the pollution stock in terms of marginal utility. Thus the share of emissions in output coincides, under optimal environmental taxation, with the share of environmental damages in total output. It can be further shown that under the emission tax $\tau\left(t\right) = \hat{\lambda}\left(t\right)$ competitive equilibrium will coincide with the social planners problem.

3.1.2 Competitive Equilibrium

The representative consumer considers the stock of pollution as exogenous and chooses consumption to maximize lifetime utility, or:

$$\max_{c(t)} \int_0^{\infty} e^{-(\rho - n)t} U\left(c, S\right) dt \tag{37}$$

subject to the budget flow constraint:

$$\dot{a} = w + ra - c - na + \tau z \tag{38}$$

where a is per capita assets, c, w, r the competitive wage rate and interest rate respectively and τz are per capita transfers due to environmental taxation, $z = Z/L$.

The representative firm maximizes profits given by (7), where by assuming that physical capital, human capital and loans are perfect substitutes as stores of value we have $r = R_K - \delta = R_H - \delta$.

In equilibrium $a = k + h$ so $\hat{a} = \hat{k} + \hat{h}$. Then the following proposition can be stated:

Proposition 1 *Under optimal environmental taxation, that is* $\tau\left(t\right) = -\lambda\left(t\right)/p\left(t\right)$, *the paths* $\left(\hat{c}\left(t\right), \hat{k}\left(t\right), S\left(t\right), Z\left(t\right)\right)$ *of a decentralized competitive equilibrium coincide with the socially-optimal paths.*

For proof see Appendix.

4 TFPG Measurement Issues

As shown above, under optimal taxation the time paths for consumption, capital and pollution at the social optimum coincide with the corresponding optimal paths in a decentralized competitive equilibrium. Our basic problem, for measurement issues, is that in practice we don't have taxation for CO_2 emissions, so we need an estimate of damages as a proxy for taxation. The only clear case where CO_2 emissions have a cost for those emitting can be found in the recently created European emission trading scheme. This however is a very recent development and our data set corresponds to the "no regulation" case. Furthermore, since we don't have taxation on emissions and therefore the share of emission taxes are not included in National Accounts, estimating TFPG using data from National Accounts, might provide biased estimates since the share of emissions damages is ignored.

TFP growth estimation in practice involves a direct implementation of growth accounting equations such as (2) using data for Y, K, L, s_K, s_L.There is a difficulty however, as indicated above, if we want to include emissions in the equation. Theory suggests that s_Z is emission damages as a share of GDP. If optimal taxation is applied then s_Z is can be measured as a share of GDP. If however emissions are not taxed, that is environment as an unpaid factor of production, then we need an independent estimate of marginal emission damages. In the absence of such estimate, the implementation of growth accounting equation like (16) or (17) using data on Y, K, L, Z, s_K, s_L, s_z is not possible. Thus, the use of the emissions as an input in the production function and the absence of emission taxation make the non econometric estimations which is usually followed, problematic. In this case, direct adjustments using independent estimates of emission damages, or econometric estimation could be used. Econometric estimation has the advantage of testing the statistical significance of emissions growth as a determinant of output growth.

4.1 Direct Adjustment using Marginal Damage Estimates

In the absence of environmental policy, but if independent estimates of CO_2 damages exist, then adjusted TFPG can be obtained by using the following two approaches:

4.1.1 First approach:

We use:

$$\hat{g}_S^i = g_S^i - s_Z^i \left(\frac{\dot{Z}}{Z} \right)_i \tag{39}$$

which can be derived directly from (3), where g_S^i is the estimation of the traditional Solow residual in country i, s_Z^i is the share of CO_2 emissions in GDP defined as $s_{zit} = \frac{p_z Z_{it}}{GDP_{it}}$, where p_z is a proxy for damages or emission taxes, and $\left(\frac{\dot{Z}}{Z}\right)_i$ is the growth of CO_2 emissions in country i. Since the share of emissions cannot be obtained from tax data, we use our theoretical result that under optimal taxation the emission's share in GDP should be equal to the share of damages from carbon dioxide in GDP. We use the estimates of carbon dioxide damages as proportion of GDP provided by the World Bank[18] to approximate s^i_Z. Then $\hat{g}^i_S$ is the new adjusted "green residual".

4.1.2 Second approach:

The second direct adjustment, is to estimate s_{zit}, the share of CO_2 emissions in GDP, using as p_z - the cost per ton of CO_2 emissions - a value of 20$ per ton of CO_2, a value that is proposed by the World Bank to represent the cost or damages per units of CO_2 emissions[19] and which also "close" to the proposed current value of the European permits market[20].

4.2 Econometric Estimation

In this case the measurement of TFP growth is based on an aggregate production function which includes CO_2 emissions as an input. This can be regarded as a more appropriate way to estimate input shares and the share of CO_2 emissions which is an unpaid factor in the production process since it's share in GDP cannot be measured by existing data in the absence of CO_2 emission taxes.

Using a Cobb-Douglas specification including emissions and human capital we obtain:[21]

$$Y = A_0 K^{a_1} H^{a_2} (AL)^{a_3} (BZ)^{a_4} \tag{40}$$

to simplify the notation in (40) we set $A_0 = 1$.Then, under constant returns to scale $(a_1 + a_2 + a_3 + a_4 = 1)$ the aggregate production function (40) in per worker terms becomes:

$$\frac{Y}{L} = \left(\frac{K}{L}\right)^{a_1} \left(\frac{H}{L}\right)^{a_2} \left(\frac{AL}{L}\right)^{a_3} \left(\frac{BZ}{L}\right)^{a_4}$$

or:

$$y = e^{(xa_3 + a_4 b)t} k^{a_1} h^{a_2} z^{a_4} \tag{41}$$

where $y = \frac{Y}{L}, k = \frac{K}{L}$,and $h = \frac{H}{L}$. Taking logs, we have the log linear form:

$$\ln y = (xa_3 + ba_4)\, t + a_1 \ln k + a_2 \ln h + a_4 \ln z \ , \ a_3 = 1 - a_1 - a_2 - a_4 \tag{42}$$

Equation (42) provides estimates of input elasticities. To have a meaningful interpretation of these elasticities as factors' shares in the absence of optimal environmental policy, we need to consider the choice of emissions in the context of the constraint optimization problem:

$$\begin{aligned} \max \Pi &= F(K, H, AL, BZ) - R_K K - R_H H - wL \\ & \quad \text{subject to} \quad Z \leq \bar{Z} \end{aligned} \tag{43}$$

[18] *Toward a measure of genuine savings*, World Development Indicators, World Bank, 2001

[19] *Towards a measure of Genuine Savings*, World Development Indicators, World Bank, 2001

[20] Current prices (2006), are reported in the range of 20euros per ton of CO_2.

[21] In the empirical analysis we use as proxy for H, an index constructed as $H_{it} = \exp(\phi(\epsilon_{jt}))$. Where ϵ_{jt} is average years in education in country i at year t, and ϕ is a piecewise linear function with zero intercept and slope 0.134 for $\epsilon_{jt} \leq 4$, 0.101 for $4 < \epsilon_{jt} \leq 8$, and 0.068 for $\epsilon_{jt} > 8$. (see Hall and Jones, 1999; Henderson and Russel (2005). Data on education were obtained from the World Bank.

where the upper bound for emissions reflect technical constraints associated with production technologies and emissions as discussed in section 2. Associating the Lagrangian multiplier μ with the constraint $Z \leq \bar{Z}$ the first order condition for the optimal input choices, including emission choice, which correspond to (43) are:

$$\frac{\partial F}{\partial K} = R_K, \ \frac{\partial F}{\partial H} = R_H, \ \frac{\partial F}{\partial L} = w, \ \frac{\partial F}{\partial Z} = \mu$$

by the envelope theorem μ is the shadow cost of emissions Z, and measures the response of maximized profits to changes in the upper bound $\bar{Z}$. This shadow cost should be distinguished from the shadow cost of the pollution stock, defined in (35), that measures the response of maximum welfare to a change in the stock of pollutants, the stock of CO_2 in our case.

Thus in the absence of environmental policy the share of the unpaid factor in equilibrium is defined as;

$$s_Z = \frac{F_Z Z}{Y} = \frac{\mu Z}{Y} \tag{44}$$

In general this will be different from the correct share $(\lambda Z)/Y$, unless $\bar{Z}$ is set at the level corresponding to the social welfare maximization path for the emissions' flow, which clearly is not the case for the period under investigation.

Therefore the elasticities obtained from the production function can be interpreted as shares associated with the constraint optimization problem (43) but not with the social welfare optimization problem (22). This has certain implications for the interpretation of any estimation results.

Given an estimate of $\hat{s}_Z$ the shadow value of emissions can be obtained as $\hat{\mu} = \hat{s}_Z (Y/Z)$ where Y/Z is the observed ouput-emissions ratio. This not however a 'true shadow cost' of pollution since the 'true shadow cost', λ, is based on a social welfare function that incorporates environmental damages.[22]

In the growth accounting exercise the contribution of CO_2 emissions on output growth using elasticities estimated from an aggregate production function, in the absence of CO_2 related environmental policy, can be interpreted in terms of emissions contributions under the existing technological constraints, and not as the 'true' contribution, when environment is properly valued by the welfare cost of using it. On the other hand this is a useful measure since it provides an indication of the impact from introducing an environmental policy that restricts emissions on aggregate output.

Actually since in the absence of a CO_2 policy it is expected that emissions constrained by technological restrictions, would be high[23], relative to the case where the socially optimal regulation is followed, the estimate of μ is expected to be low relative to λ.

In this context elasticities can be interpreted as shares, and we can set:

$$a_1 = s_K, a_2 = s_H, a_4 = s_Z \tag{45}$$

[22] There is a subtle point here associated with the shadow cost of pollutants obtained by productivity studies using mainly micro-data, where emissions or undesirable outputs are included and distance functions or linear programming methodologies are used for estimation purposes. The shadow cost estimates reflect the impact on the objective function associated with emissions, but they do not reflect damages due to emissions. So although these estimates are appropriate for studying the impact of sectoral environmental policies on firms profits or costs, they do not reflect the welfare cost of using the environment, especially if environmental policy is not well defined, or is not present during the sample period.

[23] We have unregulated profit maximization in this case.

By comparing (40) with (11) TFPG can be obtained by estimating xa_3+a_4b. In this case TFPG is approximated by the contribution of labor augmented technical change and emissions augmented technical change.

There are several ways to further specify the production function in the attempt to measure TFPG.

- With $a_4 \neq 0$, by imposing in (40) $a_2 = 0$, we obtain a production function *with emissions* but *without human capital* which has the following specification in a loglinear form:

$$\ln y = (xa_3 + a_4 b)\, t + a_1 \ln k + a_4 \ln z \tag{46}$$

With $a_4 \neq 0$, $a_2 = 0$ and by using, instead of the labour (L) in physical units, the quality adjusted labor input defined as $L_h = LH$ we have:

$$\ln y_h = (xa_3 + a_4 b)\, t + a_1 \ln k_h + a_4 \ln z_h \tag{47}$$

where all variables are measures in per 'quality adjusted' worker

- Imposing $a_2 \neq 0$ and the assumption of *equality of marginal products* between human and physical capital, we obtain:

$$\ln y = (xa_3 + a_4 b)\, t + (a_1 + a_2) \ln k + a_4 \ln z \tag{48}$$

  It is clear the for $a_4 = 0$ we have the traditional aggregate production function without emissions as an input.

Each of the production function specifications (42), (46), (47), with the elasticities interpreted as shares by (45), can be associated with a growth accounting equation. Specification (42), which is the most general has as a counterpart the growth accounting equation:

$$\frac{\dot{y}}{y} = \gamma + s_K \frac{\dot{k}}{k} + s_H \frac{\dot{h}}{h} + s_Z \frac{\dot{z}}{z} \tag{49}$$

$$\gamma = xa_3 + a_4 b \tag{50}$$

The counterparts of (46), (47) can be easily obtained by imposing appropriate restrictions on elasticities.

Using (42) or (49), TFPG can be estimated econometrically, either from the trend term xa_3+a_4b of (42) or the constant term γ of (49). Alternatively, using the estimated shares $\hat{s}_K, \hat{s}_H, \hat{s}_Z$ from (42) or (49) and average growth rates of output and inputs per worker, TFPG can be calculated from (49) as

$$\hat{\gamma} = \overline{\left(\frac{\dot{y}}{y}\right)} - \hat{s}_K \overline{\left(\frac{\dot{k}}{k}\right)} - \hat{s}_Z \overline{\left(\frac{\dot{z}}{z}\right)} \tag{51}$$

Calculations for the other specifications follow directly.

5 TFPG Estimates with Environmental Considerations

In this section we provide TFP growth estimates within the framework developed in the previous section. by using: (i) two independent estimates of CO_2 damages, and (ii) estimates obtained from econometric estimation

5.1 Direct Adjustment of Existing TFPG Estimates

5.1.1 First approach

The first approach of the direct adjustment is an attempt to adjust previous estimates of TFPG using data on CO_2 damages from the World Bank and growth of CO_2 emissions. To do that, we use (39) and the results we obtain are illustrated in *Table 1.*

Table 1

Table 1 presents the *traditional TFP* growth rates from 1960–1995 reported in Barro and Sala-i-Martin (2004). The 1st column reports the countries examined. The 2nd column contains the CO_2 growth rates of those countries and the 3rd column the share of CO_2 emission damages in GDP, (s_Z) from the World Bank estimates. The 4th column contains a multiplication of the 2nd and 3rd column to obtain the term $s_Z^i\left(\frac{\dot{Z}}{Z}\right)_i$. In the 5th column the traditional TFP growth rates are reported, while the 6th column presents the *adjusted TFP growth* for the same time period. What we observe from this first adjustment is that after the introduction of the environmental factor, TFP growth rates reduce and the reduction is based on the contribution of the environmental damage of CO_2 emissions which were excluded from previous TFPG measurements. This is a first indication that the introduction of the environment affects TFPG measurement and that the environment could be an element in growth accounting, in the sense that part of the growth of total output per worker can be explained by the growth of CO_2 per worker.

5.1.2 Second approach

A second approach to adjust TFPG measurements is by estimating s_z, the share of CO_2 emissions in GDP that we previously used as an already estimated value from the World Bank, using an approximate measure of p_z - the cost or damage per units of CO_2 emissions. The share of CO_2 emissions in GDP is defined as:

$$s_{z_{it}} = \frac{p_z Z_{it}}{GDP_{it}} \tag{52}$$

and p_z is the cost or damage per ton of CO_2 emissions. Z_{it} is CO_2 emissions for country i in year t and GDP_{it} is Gross Domestic Product produced in country i in year t. We choose for p_z, a of value of 20$ per ton of CO_2, a value that is proposed by the World Bank to represent the cost or damage per tons of CO_2 emissions[24].*Table 2* that follows presents the results for $s_{z_{it}}$ for a group of 11 countries.

Table 2

[24] Towards a measure of Genuine Savings, World Development Indicators, 2001

The price of p_z taken by the World Bank can be regarded as a proxy for the price that is assigned to the cost or damage per ton of emissions created by CO_2, in the European permits market[25]. The use of the price of 20\$ per ton of CO_2, to approximate a permits market can be justified theoretically by observing that this price (20\$ per ton of CO_2) should be the cost of taxation on CO_2 emissions, if an optimal tax was set on emissions in a competitive framework where the basic equivalence between emission taxes and emission permits holds. This equilibrium price should be equal to the marginal damages of CO_2 emissions. Although, these conditions do not hold in the actual permits market for CO_2, we believe that an approximation on these grounds could provide useful indications. Using (39), (52) and the proxy of $p_z = 20\$$, we obtain the adjusted TFPG presented in *table 3*.

Table 3

By comparing the results of the two tables, (*table 1 and table 3*), we see that when TFPG is measured through the second approach, where $p_z = 20\$$ per ton of CO_2, the adjusted TFPG (column 6) is lower relative to the first approach. This ion is due to the larger share of CO_2, the $s_{z_{it}}$ parameter, (see column 3, *table 1* and column 2, *table 3*),relative to the World Bank estimation.

5.2 Econometric Estimation of TFPG.

Following the analysis in section 5.2 we estimate the following models

Production Functions

$$
\begin{array}{ll}
PF1 & \ln y = (xa_3 + ba_4)\, t + a_1 \ln k + a_2 \ln h + a_4 \ln z \\
PF2 & \ln y = (xa_3 + a_4 b)\, t + a_1 \ln k + a_4 \ln z \\
PF3 & \ln y_h = (xa_3 + a_4 b)\, t + a_1 \ln k_h + a_4 \ln z_h
\end{array}
$$

Growth Accounting Equations

$$
\begin{array}{ll}
GA1 & \frac{\dot{y}}{y} = \gamma + a_1 \frac{\dot{k}}{k} + a_2 \frac{\dot{h}}{h} + a_4 \frac{\dot{z}}{z} \\
GA2 & \frac{\dot{y}}{y} = \gamma + a_1 \frac{\dot{k}}{k} + a_4 \frac{\dot{z}}{z} \\
GA3 & \frac{\dot{y}_h}{y_h} = \gamma + a_1 \frac{\dot{k}_h}{k_h} + a_4 \frac{\dot{z}_h}{z_h}
\end{array}
$$

Regarding the estimation of the production function and the growth accounting equations the following observations are in order:

- Estimation of the growth accounting (GA) equations represent estimations of the corresponding production functions in first differences, since we use the approximation $\dot{x}/x = \ln x_t - \ln x_{t-1}$. Thus the GA estimation could address problems associated with the stationarity of the variables in levels.
- The estimation of the production function (PF) models represents estimation of a primal model, that might suffer from endogeneity associated with inputs, implying inconsistency of direct estimators of the production function. However as it has been shown by Mundlak (1996, proposition 3), under constant returns to scale, OLS estimates of a k-input Cobb-Douglas production function, in average productivity form, with regressors in inputs-labour ratio, are consistent. This type of production function is exactly what we have in $PF1$-$PF3$.

[25] Current prices (2006), have been reported in the range of 20euros per ton of CO_2.

- To estimate the PF or the GA models we adopt a panel estimation approach with 'fixed effects' to allow for unobservable 'country effects' (e.g. Islam (1995). As shown by Mundlak (1996) this estimator applied to the primal problem is superior to the dual estimator which is applied to the dual functions. Furthermore the 'fixed effects' estimator addresses the problem of correlation between the constant term γ, which is the TFPG estimator in the GA models, with the regressors.[26]

- GA models can provide individual country TFPG estimates through the 'fixed effects' estimator. They are not however capable of identifying separately the contributions of labour augmenting and input augmenting technical change. Separate identification of the effect of the two possible sources of technical change is possible in the PF context. It should be noticed first that if both sources of technical change are modeled with the traditional way via a simple time trend, it is impossible to separate these two distinct effects using a single-stage estimation procedure. From $PF1$-$PF3$, it is evident that the parameters a_3 and α_4 cannot all be identified using a single-stage estimation procedure due to the linear dependency among some of the right-hand side variables and the resulting singularity of the variance-covariance matrix. At most either a_3 or a_4 can be identified implying respectively no technical change in conventional or damage abatement inputs (Kumbhakar, Heshmati and Hjalmarsson, 1997)[27].

  An alternative model capable to overcome the aforementioned identification problem can be applied by altering the specification of technical change in the production function. More specifically, it is possible to separate these effects by employing Baltagi and Griffin (1988) general index to model technical change in conventional inputs and traditional simple time-trend to account for changes in the productivity of damage abatement input (Karagiannis et al., 2002). In particular relation $PF1$ may take the form[28]:

$$\begin{aligned}
\ln y_{it} &= \zeta t + A(t) + a_1 \ln k_{it} + a_2 \ln h_{it} + a_4 \ln z_{it} \\
A(t) &= \sum_{t=1}^{T} (ba_4)_t D_t \\
\zeta &= xa_3
\end{aligned}$$

  and D_t is a time dummy for year t. All the relevant parameters in the above relation can be identified by imposing the restriction that as initially was suggested by Baltagi and Griffin (1988). The above specification, apart of enabling the identification of the two technical change effects

[26] This correlation has been regarded as one of the disadvantages of the regression approach in TFPG measurement (Barro 1999, Barro and Sala-i-Martin 2005).

[27] Hypothetically the Cobb-Douglas production function in relations (84) through (86) can be estimated including only the technical change in conventional inputs under a fixed or a random effects formulation and then in a second-stage individual country effects can be regressed separately against time to identify the technical change in damage abatement inputs. However, this consists only an artificial way to separate these two effects and in general is unsatisfactory solution to aforementioned identification problem. Moreover, in econometric grounds, arguments related to the efficiency of the estimated parameters surely apply compared to a single-stage estimation procedure.

[28] Relations (**??**) and (**??**) can be adjusted accordingly.

is flexible as $A(t)$ is not constrained to obey any functional form, it is capable of describing complex and sometime erratic patterns of technical change consisting of rapid bursts of rapid changes and periods of stagnation, which might be relevant when we study the emission, that is, the input augmenting technical change.

- All different specifications PF and GA were estimated using weighted least squares (WLS) in order to take into account both cross-section heteroscedasticity and contemporaneous correlation among countries in the sample. The estimation is carried out in two steps. In the first step the model is estimated via simple OLS. Using the obtained residuals the conditional country specific variance is calculated an it is used to transform both the dependent and independent variables of the second-stage regression. Specifically for each country, y_i and each element of x_i (independent variables) are divided by the estimate of the conditional standard deviation obtained from the first-stage. Then a simple OLS is performed to the transformed observations expressed as deviations of their means. This results in a feasible generalized least square estimator described by Wooldridge (2000, Ch. 8) and Greene (2003, Ch. 11)

  Estimation results are summarized in *table 4-6.*

Tables 4a, 4b show estimates of the shares s_k, s_h, s_z for models $PF1$-$PF3$., and $GA1$-$GA3$ respectively[29].

Table 4a

Table 4b

The estimates of the input shares from the PF estimation, suggest a value for capital's share between 32% and 49.6%, a share *for* CO_2 emissions between 3.3% and 7.8% and a share *for* education in the only equation which is used as a proxy for human capital, of 4.3%. When we use the GA equations, the share of capital goes down by approximately 10% while the share of emissions goes up to around 15%. The higher value of the capital share both in PF and GA estimations occur in the equation where labor input is adjusted for education with the use of the variable $L_h = LH$. In all estimations where labour is measured in physical units, the sum of capital's share and emissions' share is between 35% and 39%., an estimate within the expected range. The estimates for the CO_2 share with the interpretation given in (44) in all estimated regressions, are highly significant and in a sense that suggests a significant contribution of CO_2 emissions in output. This result seems to justify empirically the introduction of emissions as an input in the production function. Furthermore, by using (44), we can obtain the shadow cost of emissions as, $\mu = \hat{s}_z\,(Y/Z)$. Using the average values for GDP and CO_2 for the eleven countries of table 2, the shadow value of emissions μ is between 66$ and 132$ per ton of CO_2.

Table 5a, provides estimates of labor augmented technical change x, CO_2 emission augmented technical change b, and estimates of average TFPG obtained as $xa_3 + ba_4$. For the models that includes human capital (approximated by years of education) or does not include human capital at all, average TFPG

[29] PF models were also estimated by using as regressors the original regressors lagged, one period, and by instrumental variables estimation using as instruments the original regressors lagged one period. There was no substantial change in the results.

is around 1%. When we use quality adjusted labor as input, TFPG drops to 0.4%. It should be noticed here, that our methodology allows to distinguish between two different types of technical change and identifies positive emissions augmenting technology. This result can be also regarded as an empirical verification for introducing input augmenting technical change in the production function, that is the specification BZ.

Table 5*a*

Table 5b provides individual country TFPG estimates from the GA models. The estimates are obtained by adding to the overall constant of each regression the estimate of individual country fixed effect.

Table 5*b*

As shown in table 5a the average TFPG estimates are very close to the estimates obtained from the production function in table 5a.

Table 6 uses the growth accounting equations (51)and the estimated shares from the production function to obtain TFPG estimates for individual countries.

Table 6

It should be noticed that the average estimates of TFPG in table 6,, are very close to those obtained directly from the regressions using xa_3+ba_4, and the GA estimates This can be regarded as providing a confirmation of the robustness of our estimations. Negative estimates of TFPG correspond to the case where we use quality adjusted labor as input. These numbers seem to suggest that for these specific countries, the contribution of physical capital, capital quality adjusted labor and emissions to output per worker growth, exceeds the growth of output per worker.

6 Concluding Remarks

This paper aimed at formulating a new approach to Total Factor Productivity Growth measurement methodology, at a macro level, which would take into account the use of environment in the traditional TFPG measurement. We approximate the use of environment by CO_2 emissions. Our contribution at the theoretical level lies in deriving growth accounting equations with the input space of the aggregate production function augmented to include emissions and emission augmenting technical change, interpreting the emissions share in output, in the context of a completive equilibrium under optimal taxation, and in a context where emissions is an unpaid factor, that is they are not taxed. At the empirical level we provide adjustments of existing TFPG estimates when CO_2 emissions are taken into account, we estimate directly TFPG from an aggregate production function and we decompose technical change to labour augmenting and emissions augmenting technical change. Our approach can be regarded as a green TFPG Measurement methodology.

Our results an average TFPG for the period 1965-1990 for the countries under examination of the order of 1%. They also suggest that emissions in the form of CO_2 is a statistically significant input in the aggregate production function and that emission augmenting technical change coexist with labour augmenting technical change. This implies that the use of the environment approximated by CO_2 emissions, which is an unpaid factor, contributes to the growth of output along with physical capital, human capital, and labour, and its contribution should be accounted in the context of a "green TFPG" or a "green residual estimation". It should be also noted that the environment's contribution we estimated through the production function analysis might underestimate or overestimate the "socially optimal contribution", which is associated with an optimal tax determined by marginal environmental damages along the optimal path. If marginal damages are high the socially optimal use of the environment in the growth process, should be small, while the opposite holds for low marginal damages. If in the absence of optimal environmental policy this contribution is sizable, and our results suggest that the CO_2 emissions contribution is statistically significant with a share in output which could be as high as 14%, then excess use of the environment as an input might question the eventual sustainability of the current growth process. For example if, after solving the social planner's problem, we have an estimate of λ, the true shadow value of the CO_2, and calculate emissions' share, s_Z as $(\lambda Z)/Y$, then the growth accounting equation (16) might produce a negative result. This result can be interpreted as an indication that total use of resources, including the "unpaid" one properly valued, exceeds the output growth generated by these resources. In this case development that uses "unpaid" factors is not sustainable.[30]

Our future research includes TFPG estimates, within this new framework, for developing countries, introduction of stock variables into the aggregate production function, use of our production function estimates along with damage functions for CO_2 to actually solve the social planners problem, and define the structure and the parameters of value functions, and at a more general level reformulating some of the resent empirical approaches to growth to take into account possible unpaid, and damage generating, factors of production. We hope that this approach will enhance growth empirics by incorporating the environmental dimension in a meaningful way.

[30] Along the socially-optimal path this will not happen since the use of the "unpaid" factor - the environment - will be determined by its true shadow cost.

Appendix

Derivation of the Social Planner's Problem

Capital accumulation in per worker terms, assuming that the two capital goods depreciate at the same constant rate (Barro and Sala-i-Martin, 2004), is given by:

$$\dot{k} + \dot{h} = y - c - (\eta + \delta)(k + h) \tag{53}$$

Set $k = \hat{k}e^{\xi t}$ and $h = \hat{h}e^{\xi t}$, $c = \hat{c}e^{\xi t}$ so that $\dot{k} = \dot{\hat{k}}e^{\xi t} + \xi \hat{k}e^{\xi t}$ and $\dot{h} = \dot{\hat{h}}e^{\xi t} + \xi \hat{h}e^{\xi t}$. Substituting $\dot{k}$ and $\dot{h}$ in (53) we obtain:

$$\dot{\hat{k}}e^{\xi t} + \xi \hat{k}e^{\xi t} + \dot{\hat{h}}e^{\xi t} + \xi \hat{h}e^{\xi t} = e^{\zeta t}(\hat{k}e^{\xi t})^{a_1}(\hat{h}e^{\xi t})^{a_2} Z^{a_4} - \hat{c}e^{\xi t} - (\eta + \delta)(\hat{k}e^{\xi t} + \hat{h}e^{\xi t})$$

dividing by $e^{\xi t}$:

$$\begin{aligned} \dot{\hat{k}} + \dot{\hat{h}} &= e^{-\xi t}\left(e^{\zeta t}\hat{k}^{a_1}e^{\xi t a_1}\hat{h}^{a_2}e^{a_2 \xi t}Z^{a_4}\right) - \hat{c} - (\eta + \delta + \xi)(\hat{k} + \hat{h}), \text{ or} \\ \dot{\hat{k}} + \dot{\hat{h}} &= e^{(\zeta - \xi + a_1\xi + a_2\xi)t}\hat{k}^{a_1}\hat{h}^{a_2}Z^{a_4} - \hat{c} - (\eta + \delta + \xi)(\hat{k} + \hat{h}) \end{aligned}$$

to make the above equation time independent we choose ξ such that $\zeta - \xi + a_1\xi + a_2\xi = 0$ or $\xi = \frac{\zeta}{1 - a_1 - a_2} = \frac{x a_3 + a_4(b-n)}{1 - a_1 - a_2}$

$$\dot{\hat{k}} + \dot{\hat{h}} = \hat{k}^{a_1}\hat{h}^{a_2}Z^{a_4} - \hat{c} - (\eta + \delta + \xi)(\hat{k} + \hat{h}) \tag{54}$$

Assuming as above that the allocation between physical and human capital is such that the marginal products for each type of capital are equated in equilibrium if we use both forms of investment, we have using (13) that[31]:

$$a_1 \frac{\hat{y}_t}{\hat{k}_t} - \delta = a_2 \frac{\hat{y}_t}{\hat{h}_t} - \delta \tag{55}$$

The equality between marginal products implies a one to one relationship between physical and human capital, or:

$$\hat{h} = \frac{a_2}{a_1}\hat{k}, \; \dot{\hat{h}} = \frac{a_2}{a_1}\dot{\hat{k}} \tag{56}$$

Using (56) in (54) we obtain:

$$\dot{\hat{k}} + \frac{a_2}{a_1}\dot{\hat{k}} = \hat{k}^{a_1}\left(\frac{a_2}{a_1}\hat{k}\right)^{a_2} Z^{a_4} - \hat{c} - (\eta + \delta + \xi)\left(\hat{k} + \frac{a_2}{a_1}\hat{k}\right)$$

$$\begin{aligned} \dot{\hat{k}} &= \tilde{A}\hat{k}^{\beta}Z^{a_4} - \hat{c} - (\eta + \delta + \xi)\,\hat{k}, \\ \tilde{A} &= \left(\frac{a_2^{a_2}a_1}{a_1^{a_2}(a_1 + a_2)}\right), \; \beta = a_1 + a_2 \end{aligned} \tag{57}$$

[31] This substitution is convenient since by adopting it we do not need a seperate state equation for human capital. It does not however affect the basic results of this section regarding the interpretation of the emissions share in output.

Considering a utility function $U(c,S) = \frac{1}{1-\theta}c^{1-\theta}S^{-\gamma} \quad \theta,\gamma > 0$ we obtain using the substitution $c = \hat{c}e^{\xi t}$.

$$\begin{aligned} U(c,S) &= \frac{1}{1-\theta}c^{1-\theta}S^{-\gamma} = \frac{1}{1-\theta}\left(\hat{c}e^{\xi t}\right)^{1-\theta}S^{-\gamma} = \\ &= e^{(1-\theta)\xi t}\frac{1}{1-\theta}\hat{c}^{1-\theta}S^{-\gamma} = e^{(1-\theta)\xi t}U(\hat{c},S) \end{aligned} \tag{58}$$

Using (21), (58), (20), and (57) the social planners problem can be written as (22) ■

Proof of Proposition 1:. *Consumers:* Defining the current value Hamiltonian for the representative problem as:

$$H = U(c,S) + \pi(w + ra - c + na + \tau z) \tag{59}$$

standard optimality conditions imply:

$$U_c(c,S) = \pi \ , \ U_{cc}(c,S)\dot{c} = \dot{\pi} \tag{60}$$

$$\dot{\pi} = (\rho - r)\pi \text{ or} \tag{61}$$

$$\frac{\dot{c}}{c} = \frac{1}{\theta}(r-\rho) \tag{62}$$

*Firms:*The profit function for the firm can be written in per worker terms, using the Cobb-Douglas specification and setting $k = \hat{k}e^{\xi t}$, $h = \hat{h}e^{\xi t}$, and $\zeta - \xi + a_1\xi + a_2\xi = 0$, $\xi = \zeta - a_1\xi - a_2\xi$ as:

$$\Pi = F(K,H,E,X) - R_K K - R_H H - wL - \tau Z \tag{63}$$

or

$$\begin{aligned} \frac{\Pi}{L} &= e^{\zeta t}\hat{k}^{a_1}\hat{h}^{a_2}Z^{a_4} - R_K\hat{k} - R_H\hat{h} - w - \tau z \\ \frac{\Pi}{L} &= e^{\xi t}\hat{k}^{a_1}\hat{h}^{a_2}Z^{a_4} - R_K\hat{k} - R_H\hat{h} - w - \tau z \end{aligned}$$

$$\tilde{\pi} \equiv \frac{\Pi}{L} = e^{\xi t}\left[f\left(\hat{k},\hat{h},Z\right) - R_K\hat{k} - R_H\hat{h} - we^{-\xi t} - \tau ze^{-\xi t}\right], \ z = \frac{Z}{L} \tag{64}$$

In equilibrium firms take R_K, R_H, w, and τ as given and maximize for any given level $\hat{l} = Le^{\xi t}$ by setting:

$$f_{\hat{k}} = R_K = r + \delta \tag{65}$$

$$f_{\hat{h}} = R_H = r + \delta \tag{66}$$

$$f_Z = \frac{\tau}{\hat{l}} \Rightarrow f_Z\hat{l} = \tau^{32} \tag{67}$$

$$e^{\xi t}\left[f\left(\hat{k},\hat{h},Z\right) - f_{\hat{k}}\hat{k} - f_{\hat{h}}\hat{h} - \left(f_Z\hat{l}\right)ze^{-\xi t}\right] = w \tag{68}$$

The wage w equals the marginal value of labor and ensures that profits are zero in equilibrium, since by substituting (65)-(68) into (64) we obtain:

$$\begin{aligned} f\left(\hat{k},\hat{h},Z\right) - R_K\hat{k} - R_H\hat{h} - e^{\xi t}\left[f\left(\hat{k},\hat{h},Z\right) - f_{\hat{k}}\hat{k} - f_{\hat{h}}\hat{h} - \tau ze^{-\xi t}\right]e^{-\xi t} - \tau ze^{-\xi t} &= \\ f\left(\hat{k},\hat{h},Z\right) - f_{\hat{k}}\hat{k} - f_{\hat{h}}\hat{h} - f\left(\hat{k},\hat{h},Z\right) + f_{\hat{k}}\hat{k} + f_{\hat{h}}\hat{h} + \left(f_Z\hat{l}\right)ze^{-\xi t} - \left(f_Z\hat{l}\right)ze^{-\xi t} &= 0 \end{aligned}$$

Equilibrium: In equilibrium $a = k + h$ so $\hat{a} = \hat{k} + \hat{h}$, then the flow budget constraint :

$$\dot{a} = w + ra - c - na + \tau z \tag{69}$$

can be written as:

$$\dot{k} + \dot{h} = w + r(k + h) - c - n(k + h) + \tau z \tag{70}$$

Setting as before $k = \hat{k}e^{\xi t}$ and $h = \hat{h}e^{\xi t}$, $c = \hat{c}e^{\xi t}$, and taking the time derivatives of k and h we obtain:

$$\dot{\hat{k}}e^{\xi t} + \xi\hat{k}e^{\xi t} + \dot{\hat{h}}e^{\xi t} + \xi\hat{h}e^{\xi t} = \tag{71}$$
$$w + r\left(\hat{k}e^{\xi t} + \hat{h}e^{\xi t}\right) - \hat{c}e^{\xi t} - n\left(\hat{k}e^{\xi t} + \hat{h}e^{\xi t}\right) + \tau z \tag{72}$$

substituting (65)-(68) into (70), and using in equilibrium $r = f_{\hat{k}} - \delta = f_{\hat{h}} - \delta$, $f_Z\hat{l} = \tau$, $\hat{l} = Le^{\xi t}$ we obtain:

$$\dot{\hat{k}}e^{\xi t} + \xi\hat{k}e^{\xi t} + \dot{\hat{h}}e^{\xi t} + \xi\hat{h}e^{\xi t} = \tag{73}$$
$$e^{\xi t}\left[f\left(\hat{k}, \hat{h}, Z\right) - f_{\hat{k}}\hat{k} - f_{\hat{h}}\hat{h} - \left(f_Z\hat{l}\right)ze^{-\xi t}\right] + \left(f_{\hat{k}} - \delta\right)\hat{k}e^{\xi t} + \tag{74}$$
$$\left(f_{\hat{h}} - \delta\right)\hat{h}e^{\xi t} - \hat{c}e^{\xi t} - n\left(\hat{k}e^{\xi t} + \hat{h}e^{\xi t}\right) + \left(f_Z\hat{l}\right)z \tag{75}$$

but since $\left(f_Z\hat{l}\right) = f_Z Le^{\xi t}$ the term $\left(f_Z\hat{l}\right)ze^{-\xi t}$ in (74) becomes $f_Z Le^{\xi t}ze^{-\xi t} = f_Z Lz = f_Z Z$, while the term $\left(f_Z\hat{l}\right)z$ in (75) becomes $f_Z Le^{\xi t}z = f_Z Ze^{\xi t}$. Dividing by $e^{\xi t}$ we obtain as in (54), under the Cobb-Douglas assumption

$$\dot{\hat{k}} + \dot{\hat{h}} = \hat{k}^{a_1}\hat{h}^{a_2}Z^{a_4} - \hat{c} - (\eta + \delta + \xi)(\hat{k} + \hat{h}) \tag{76}$$

Using as above the assumption that in equilibrium the allocation between physical and human capital is such that the marginal products for each type of capital are equated if we use both forms of investment, we have as before $a_1\frac{\hat{y}_t}{\hat{k}_t} - \delta = a_2\frac{\hat{y}_t}{\hat{h}_t} - \delta$ and $\hat{h} = \frac{a_2}{a_1}\hat{k}$, $\dot{\hat{h}} = \frac{a_2}{a_1}\dot{\hat{k}}$. Then (76) becomes

$$\dot{\hat{k}} = f\left(\hat{k}, Z\right) - \hat{c} - (\eta + \delta + \xi)\hat{k} \ \ , \ \ f\left(\hat{k}, Z\right) = s\tilde{A}\hat{k}^{\beta}Z^{a_4} \tag{77}$$

which is the social planners transition equation.

Setting $c = \hat{c}e^{\xi t}$ and $\dot{c} = \xi\hat{c}e^{\xi t} + \dot{\hat{c}}e^{\xi t}$ into (62) we obtain

$$\frac{\dot{\hat{c}}}{\hat{c}} = \frac{1}{\theta}\left[f_{\hat{k}}\left(\hat{k}, Z\right) - \rho - \delta - \xi\theta\right] \tag{78}$$

Under optimal taxation we have from the social planner's problem that $f_Z\left(\hat{k}, Z\right) = -\lambda/p = \tau$, with $p = U_{\hat{c}}(\hat{c}, S)$, then $Z = g\left(\hat{k}, \lambda, p\right)$. Substituting Z into the equation above and into (20) we obtain

$$\frac{\dot{\hat{c}}}{\hat{c}} = \frac{1}{\theta}\left[f_{\hat{k}}\left(\hat{k}, g\left(\hat{k}, \lambda, p\right)\right) - \rho - \delta - \xi\theta\right], \tag{79}$$
$$\dot{S} = g\left(\hat{k}, \lambda\right) - mS \tag{80}$$

The dynamic system (77), (79) and (80) determines the evolution of $\left(\hat{c}, \hat{k}, S\right)$ in a decentralized competitive equilibrium under optimal emission taxation. By comparing them with (30), (32) and (33) it is clear that the path of the decentralized competitive equilibrium under optimal emission taxation coincides with the socially optimal path. ■ ■

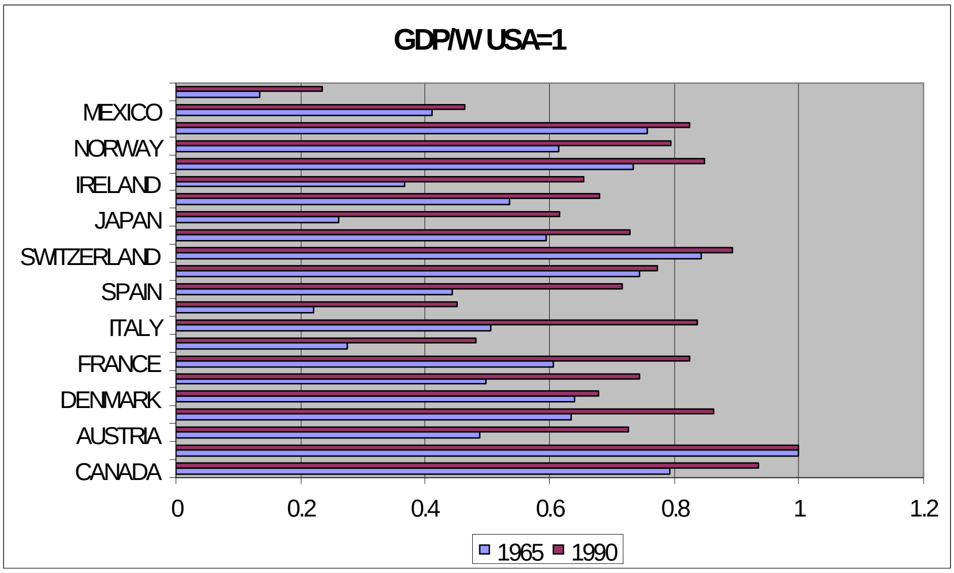

Figure 1: GDP per worker in 1965 and 1990 (USA=1)

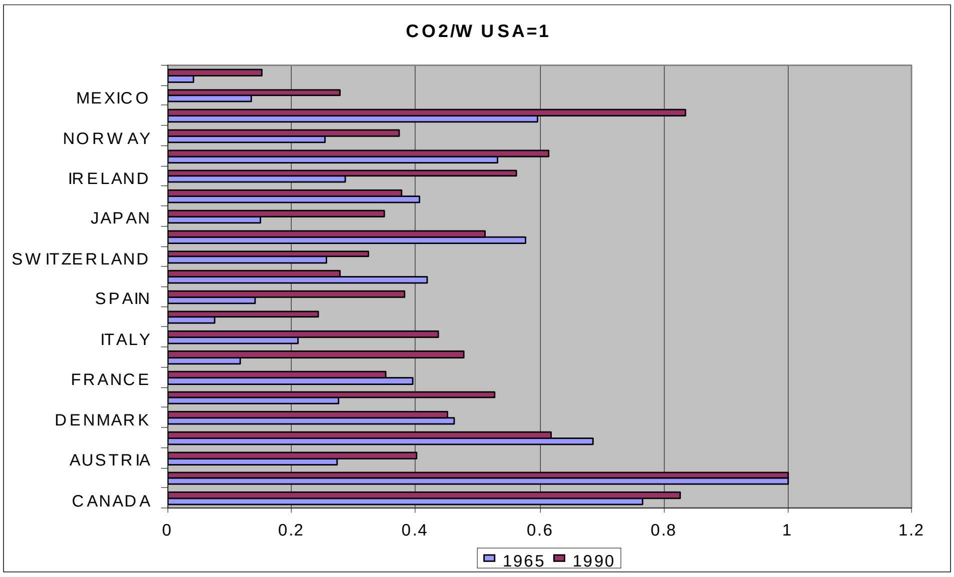

Figure 2: CO_2 per worker in 1965 and 1990 (USA=1)

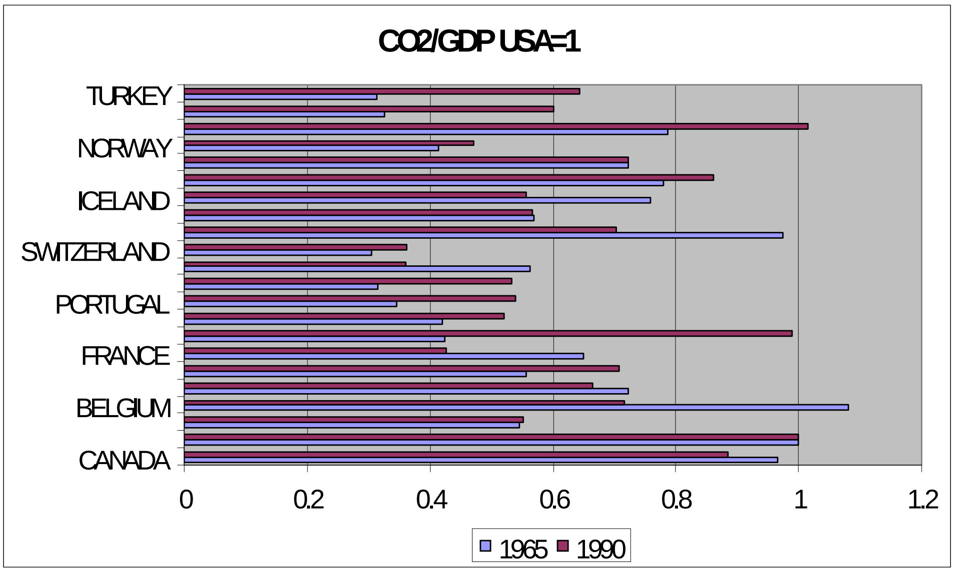

Figure 3: CO_2/GDP in 1965 and 1990 (USA=1)

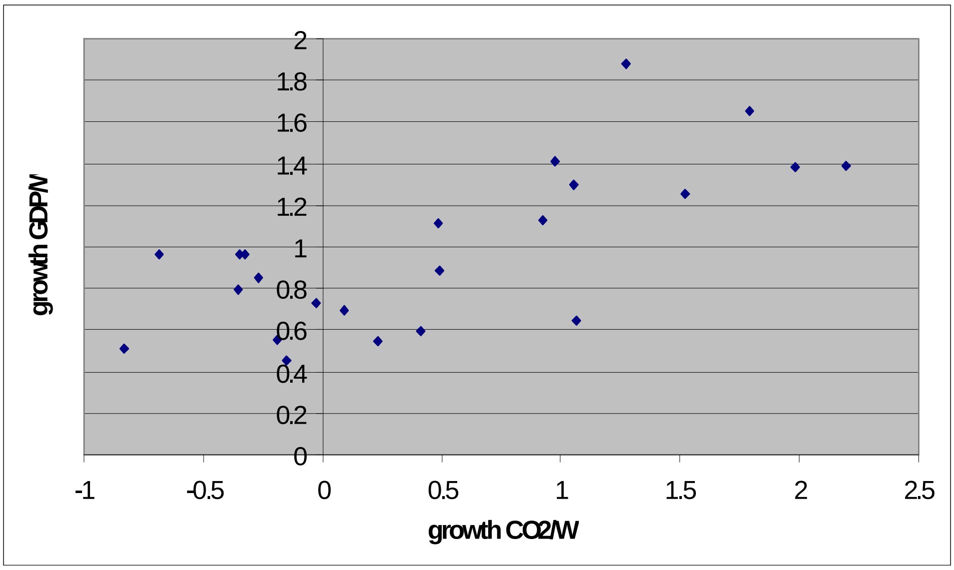

Figure 4: Growth of GDP per worker vs growth of CO_2 per worker.

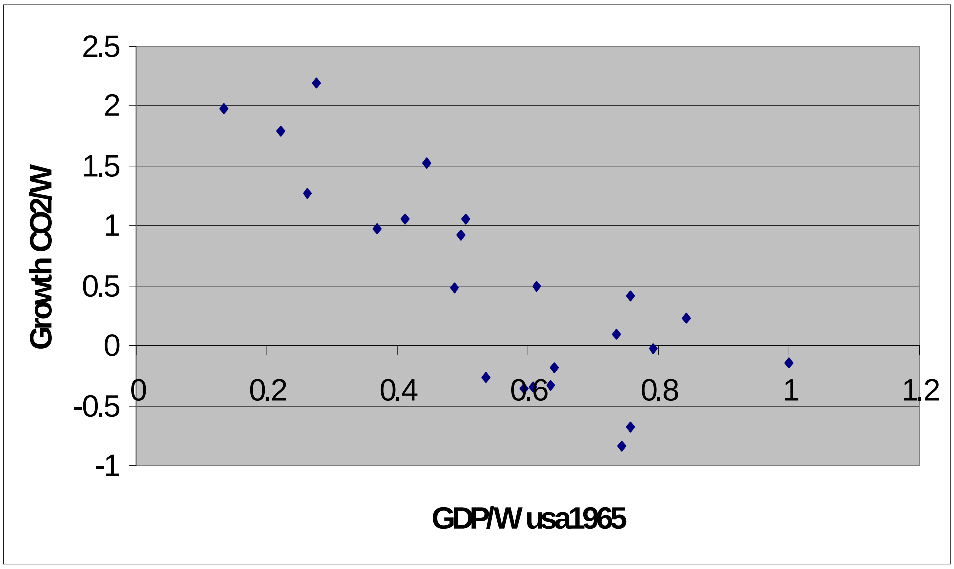

Figure 5: Growth CO_2/W vs GDP/W (GDP/W for USA=1 at 1965)

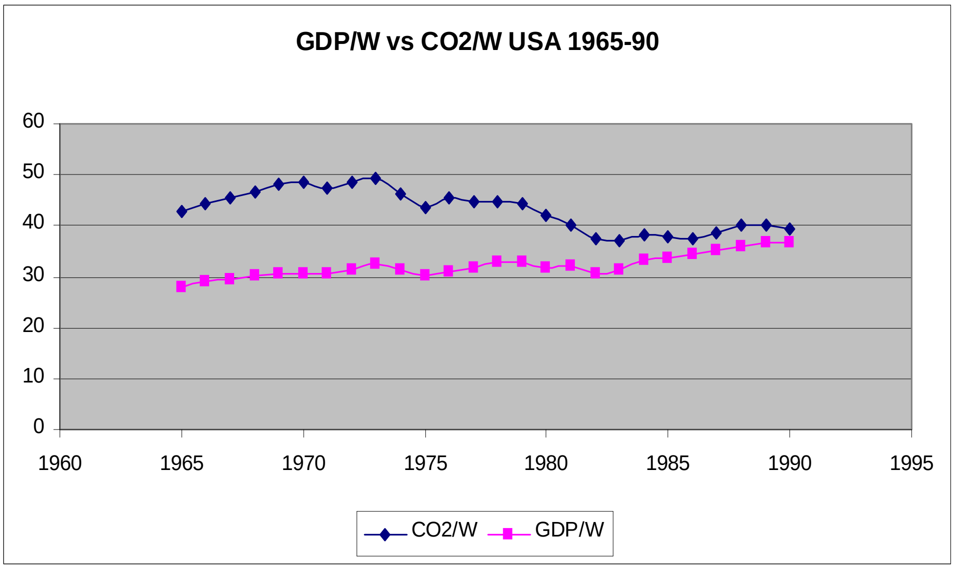

Figure 6: GDP/W, CO2/W USA 1965-90

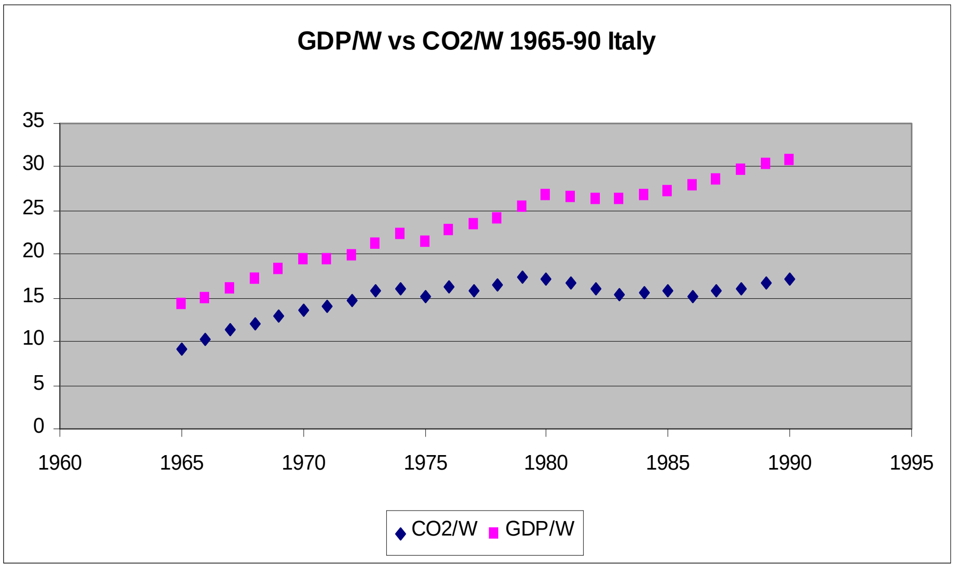

Figure 7: GDP/W, CO2/W Italy 1965-90

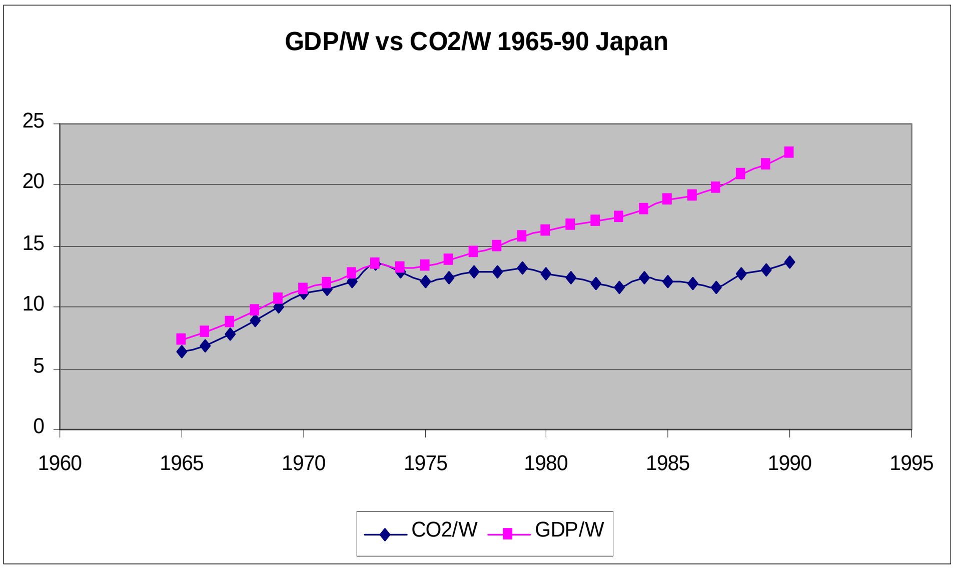

Figure 8: GDP/W, CO2/W 1965-90 Japan

Table 1: Traditional and Adjusted *TFP* growth rates from 1960–1995 using s_z from the World Bank

(1) Countries	(2) CO_2 growth rates	(3) S_Z	(4)= (2)*(3)	**(5) TradTFP growth rates 1960-95**	**(6)Adjus TFP growth**
CANADA	0.0248	0.005	0.00012	**0.0057**	**0.0056**
U.S.A.	0.0160	0.004	0.00006	**0.0076**	**0.0075**
FRANCE	0.0069	0.001	0.00006	**0.013**	**0.0129**
ITALY	0.0365	0.002	0.00007	**0.0153**	**0.0152**
U.K.	-0.0021	0.002	-0.000004	**0.008**	**0.008**
JAPAN	0.0441	0.002	0.000008	**0.0265**	**0.0264**
HONGKON	0.0643	0.001	0.000006	**0.023**	**0.0229**
MEXICO	0.0450	0.005	0.00022	**0.0113**	**0.0111**
ARGENTIN	0.0273	0.003	0.000008	**0.0054**	**0.0053**
CHILE	0.0328	0.004	0.000131	**0.0138**	**0.0136**
PERU	0.0321	0.003	0.000009	**-0.0062**	**-0.0062**

Table 2: $s_{z_{it}}$ for a group of 11 countries.

Countries	$s_{z_{it}}$
CANADA	0.02415
U.S.A.	0.02661
FRANCE	0.01460
ITALY	0.01284
U.K	0.02130
JAPAN	0.01556
HONGKONG	0.00789
MEXICO	0.01216
ARGENTINA	0.01223
CHILE	0.01258
PERU	0.00883
Average	0.015341

Table 3: Traditional and Adjusted TFP growth 1960-95 with $p_z = 20\$$.

(1)Countries	(2)s_{zit}	(3)CO_2growth	(4)=(2)*(3)	(5) Trad TFPG	(6) AdjustTFPG
CANADA	0.02415	0.02127	0.000513	0.0057	0.0052
U.S.A.	0.02661	0.01320	0.000351	0.0076	0.0072
FRANCE	0.01460	0.00042	0.000006	0.013	0.013
ITALY	0.01284	0.02975	0.000382	0.0153	0.0149
U.K	0.02130	−0.00354	−0.000075	0.008	0.008
JAPAN	0.01556	0.04074	0.000634	0.0265	0.0258
HONGKONG	0.00789	0.06786	0.000536	0.023	0.0225
MEXICO	0.01216	0.05605	0.000682	0.0113	0.0106
ARGENTINA	0.01223	0.02468	0.00030	0.0054	0.0051
CHILE	0.01258	0.02746	0.000345	0.0138	0.0134
PERU	0.00883	0.02410	0.000212	−0.0062	−0.0064

Table4a− *Production Functions*

	$PF1$	$PF2$	$PF3$
c	−0.25711	−0.20460	−0.08791
$a_1 = s_k$	0.32199	0.32597	0.49580
$a_4 = s_z$	0.07603	0.07774	0.03294
$a_2 = s_h$	0.04256	−	−
ba_4	0.002059	0.002064	0.0028012
xa_3	0.009169	0.008611	0.000593
R^2	0.99	0.99	0.99
DW	2.00875	2.02950	2.00932

All coefficients are significant at 1% level

Table4b− *Growth Accounting Equations**

	$GA1$	$GA2$	$GA3$
$a_1 = s_k$	0.21494	0.21485	0.44633
$a_4 = s_z$	0.14407	0.14448	0.15488
$a_2 = s_h$	0.02405	$-$	$-$
R^2	0.89	0.89	0.97
DW	2.05828	2.05849	2.06371

All coefficients are significant at 1% level

(*) We do not report the constant term since the overall constant plus with the fixed effect estimator for each county define the TFPG for this country. These estimates are reported in table 6b.

Table 5a:$-$ *TFPG estimates using the production function*

	xa_3	ba_4	x	b	$TFPG$
$PF1$	0.00917	0.00206	0.01639	0.02708	0.01122
$PF2$	0.00861	0.00206	0.01444	0.02656	0.01067
$PF3$	0.00059	0.00280	0.00126	0.08504	0.00339

Table 5b: *TFPG estimates using the growth accounting equations*

Countries	$GA1$	$GA2$	$GA3$
CANADA	0.009825	0.009452	-0.00057
U.S.A.	0.005149	0.004922	-0.003864
AUSTRIA	0.011807	0.011726	-0.00208
BELGIUM	0.017204	0.01691	0.01179
DENMARK	0.007932	0.007759	-0.000514
FINLAND	0.017121	0.016993	0.007033
FRANCE	0.014472	0.014404	0.002705
GREECE	0.014883	0.015025	-0.001442
ITALY	0.018542	0.018566	0.007159
LUXEMBOURG	0.021252	0.021199	0.013261
PORTUGAL	0.023597	0.023525	0.009182
SPAIN	0.010792	0.010754	-0.00578
SWEDEN	0.009019	0.00885	0.000109
SWITZERLAND	0.005414	0.005204	-0.002261
U.K	0.01332	0.013055	0.007811
JAPAN	0.023158	0.022758	0.007299
ICELAND	0.011533	0.010966	0.002536
IRELAND	0.022938	0.022673	0.013404
NETHERLANDS	0.010253	0.00991	0.003105
NORWAY	0.018458	0.018253	0.01395
AUSTRALIA	0.007183	0.006713	0.000304
MEXICO	0.005397	0.004921	-0.006345
TURKEY	0.014218	0.013845	0.000786
Averages	0.013629	0.013408	0.003373

Table 6: *TFPG calculations using factor shares estimates from the production function*

Countries	$PF1$	$PF2$	$PF3$
CANADA	0.00657	0.005774	−0.002668
U.S.A.	0.00221	0.001713	−0.006308
AUSTRIA	0.00659	0.006204	−0.003676
BELGIUM	0.01329	0.012640	0.009634
DENMARK	0.00399	0.003563	−0.003396
FINLAND	0.01424	0.013842	0.0070440
FRANCE	0.00959	0.009315	−0.000681
GREECE	0.01306	0.013059	0.001541
ITALY	0.01589	0.015753	0.007459
LUXEMBOURG	0.01761	0.017429	0.009761
PORTUGAL	0.02146	0.021091	0.011636
SPAIN	0.00682	0.006479	−0.004975
SWEDEN	0.00356	0.003142	−0.004999
SWITZERLAND	0.00230	0.001786	−0.003274
U.K	0.00931	0.008716	0.005570
JAPAN	0.01724	0.016188	0.007519
ICELAND	0.00705	0.005885	−0.000350
IRELAND	0.01981	0.019137	0.013902
NETHERLANDS	0.00739	0.006656	0.001841
NORWAY	0.01816	0.017760	0.013792
AUSTRALIA	0.00578	0.004844	0.000414
MEXICO	0.00441	0.003427	−0.00555
TURKEY	0.01253	0.011634	0.00356
Averages	0.010385	0.0098277	0.002513

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