Productive Base Sustainability and Global Warming

Dimitra Vouvaki*and Anastasios Xepapadeas†

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Abstract

Climate change is one of the most urgent and severe problems of the international agenda and one of the basic factors that determine sustainability conditions. This paper attempts to reveal the connection between productive base sustainability for two large groups of countries, developed and developing, and the state of the environment which is proxied by the stock of CO_2 which is mostly responsible for the creation of the global warming phenomenon. Three different policy scenaria for the evolution of global CO_2 emissions confirm empirically the strong association of the environment with productive base sustainability and provide the foundations for the formulation of sustainability policy.

Keywords: Productive base sustainability, current change in social welfare, accounting prices, non-optimizing economies, developed countries, developing countries, policy implications.

JEL Classification:

1 Introduction

One of the most urgent and severe problems that occupy the international agenda today, is the rapid climate change and the global warming phenomenon. Global temperature increase, is associated with the greenhouse effect and

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*University of Crete, Department of Economics, University Campus, 74 100 Rethymno, Greece, e-mail: dimitra@econ.soc.uoc.gr. This paper is part of the 03ED375 research project, implemented within the framework of "Reincforcement Programme of Human Research Manpower" (PENED) and co-financed by National and Community Funds (25% from the Greek Ministry of Development - General Secreteriat of Research and Technology and 75% from EU. - European Social Fund).

†University of Crete, Department of Economics, University Campus, 74 100 Rethymno, Greece, e-mail: xepapad@econ.soc.uoc.gr. A. Xepapadeas acknowledges support from Marie Curie Development Host Fellowship of the European Community's Fifth Framework Programme (HPMD-CT-2000-00036) and this paper is also part of the 03ED375 research project, implemented within the framework of "Reincforcement Programme of Human Research Manpower" (PENED) and co-financed by National and Community Funds (25% from the Greek Ministry of Development - General Secreteriat of Research and Technology and 75% from EU. - European Social Fund).

is likely to trigger serious consequences for the state of the earth and for humankind[1]. The European Commission reports that during the last century, the Earth's average surface temperature rose by around 0.6 degrees Centigrade[2]. This generates a number of problems in all aspects of life and activities. Extreme weather events, endangerment of species, the rise of the sea level which will endanger coastal areas and small islands, important effects for agriculture, the farming sector etc. It is nowadays's general knowledge that most of the global warming is attributable to human activities[3]. This includes the burning of fossil fuels which cause carbon dioxide (CO_2) emissions which is considered to be the main factor responsible for climate change, as well as the emissions of other 'greenhouse' gases[4]. This direct link between the environment and economic activity points out the destructive results of the inconsiderate use of the environmental resources by humans. Current reports (IPCC report[5], the Stern Report) present different possible future scenaria that include more or less pessimistic predictions for the years to come, depending on the way we decide to handle and control the global warming phenomenon today and in the immediate future[6]. The prospects are not very optimistic if action is not taken now. If the implementation of current policies that do not pay any attention to the global warming is continued, this phenomenon will be intensified. The various reports[7] on this issue identify the urgent need for action now in order to build and maintain a development process that could be characterized as sustainable. Thus the global warming phenomenon which is clearly interlinked with environmental sustainability, if not controlled by governments and policy makers, can cause irreversible damage to future generations.

Based on these concepts, the paper's main objective is to relate global carbon dioxide (CO_2) concentration and emissions that lead to global warming and climate change, to a concept of productive base sustainability and to approximate empirically the impact of environmental degradation on current social welfare (CSW). Sustainability though, has been regarded as the current and future goal to be achieved. The idea that each generation should bequeath to each successors at least the productive base it inherited from its predecessors, is the cornerstone of sustainable development. Thus, this paper has two basic goals. First, it attempts to model the Brutland Report's concept[8] in terms of

[1] The IPCC Report, European Commission Report 2006, The Stern Report.

[2] NASA reports that 2006 was the fifth warmest year on record and 2007 will likely be even warmer - possibly the warmest year in the history of instrumental measurements. Over the past 30 years Earth has warmed by about 0.6 degrees Centigrade or 1.08 degrees Fahrenheit.

[3] The IPCC Report, Technical Summary

[4] As has been indicated by the European Commission Report, 2006.

[5] IPCC Special Report on Emissions Scenarios

[6] "The current level or stock of greenhouse gases in the atmosphere is equivalent to around 430 parts per million (ppm) CO_2, compared with only 280ppm before the Industrial Revolution. These concentrations have already caused the world to warm by more than half a degree Celsius and will lead to at least a further half degree warming over the next few decades, because of the inertia in the climate system". The Stern Review: The Economics of Climate Change, Executive Summary pg. iii.

[7] Kyoto Protocol, IPCC report, the Stern Report

[8] "Sustainable development is the development that meets the needs of the present without

changes in *current social welfare (CCSW) conditions* by taking into account the way the climate change contributes to current social welfare. The second aim is to provide empirical results for two large groups of countries (developed and developing) obtained directly from the application of our theoretical model and this way to establish and estimate a link between CCSW and global warming. Social welfare (SW) measures the current and future state of human well being which is closely associated with the state of the earth and sustainable development. In order to define a measure of CCSW conditions we use the time derivative of social welfare function which provides, according to Arrow et al. (2003), a measure of the rate of change of the economy's current social welfare or a measure of genuine investment at this time. In order to measure whether an economy is currently characterized by *positive* changes in social welfare and thus positive genuine investment, we formulate a criterion that measures sustainability in productive base terms. If the time derivative of a Ramsey-Koopmans Social Welfare Function (R-K SWF) at time t is positive, then an economy is currently productive base sustainable and genuine investment is also positive[9]. In this sense, sustainable development is measured as the change in productive capacity. Reductions in productive capacity can be captured by negative genuine investment and imply that we leave less productive capacity to future generations to satisfy their needs. More specifically, if an economy is not currently productive base sustainable, then the time derivative of the R-K SWF at time t is negative and genuine investment is also negative. Negative genuine investment (or savings) imply that total wealth is in decline and policies that lead to persistently negative genuine savings are unsustainable[10]. This can be considered as a *productive base approach* to sustainable development.

Following this methodological approach, we develop our model based on the case of non optimizing economies[11] that we believe fits best current economic structures. We estimate CCSW conditions for two large groups of 23 developed[12] and 21 developing economies[13] by taking into account one of the basic environmental factors that can be held accountable for the global warming phenomenon, namely CO_2 emissions[14]. Given the damages that CO_2 emissions

compromising the ability of future generations to meet their own needs". The Brutland Report.

[9] Arrow et all., (2003).

[10] The World Bank (2006, Ch. 3). Asheim (1994), Hamilton and Clemens (1999), Pezzey (2004b), show that negative genuine savings at t, that is declining social welfare, implies unsustainability in individual utility terms in optimizing economy. This result however has not been shown to hold in a more general non-optimizing context.

[11] A non-optimizing economy is an economy where goverment whether by design or by incompetence does not choose policies that maximize intergenerational welfare. (Arrow et all., 2003).

[12] 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.

[13] The 21 Developing countries used in our analysis are the following: Peru, Thailand, Paraguay, Morocco, Dominican Republic, Guatemala, Honduras, Jamaica, Bolivia, Colombia, Ecuador, Iran, Srilanka, Syria, Yugoslavia, India, Kenya, Madagascar, Malawi, Sierra Leone, Zimbabwe.

[14] There are two basic reasons why we use CO_2 emissions in this paper as the basic con-

and other GHG's create, our goal is first to define theoretically and then to estimate the CCSW for each one of the countries we analyze (developed and developing). Under the current production structure, the realized CO_2 emission time paths, the currently estimated CO_2 damages and the projected emission time paths[15], the CCSW obtained are negative. When CO_2 emission time paths are considered as a policy parameter and when we change them so that emissions do not increase over time, CCSW becomes positive. We believe that this theoretical framework is capable of providing policy suggestions regarding the productive base sustainability implied directly or indirectly from the empirical implementation of the model.

The next of the paper is organized as follows. Section 2, describes our basic model. This model allows us to define a productive base sustainability criterion or the current change in social welfare conditions. We use a production function that includes capital along with technical change and CO_2 emissions as inputs in production. Section 3 defines the value function and the accounting prices of our model under the assumption of the global warming phenomenon. Section 4, defines the productive base sustainability criterion or the current change on social welfare conditions criterion and the next section presents the parameters and the empirical results for each one of the two large group of countries we analyze. Section 6 presents our empirical estimations and section 7 presents some policy implications that arise from the empirical application and the results of our model. The last section concludes.

2 Descriptive growth with emissions as an input

Starting from the concept of a non-optimizing economy in the sense that while firms maximize profits, consumers save a fixed proportion of their income, our attempt is to provide a measure of current changes in social welfare. We consider a stylized economy where the productive base includes a list of assets such as physical capital, human capital, and natural capital, along with labor augmenting (Harrod neutral) technical change and emission augmenting technical change. We consider the earth's atmosphere as a component of social overhead capital (Uzawa, 2003) which can play the role of natural capital. In this case natural capital is associated with the stock of accumulated GHG's and CO_2 emissions along with other GHG's can be thought as a reduction of this social capital - a form of disinvestment. Thus the impact of natural capital in our model is captured by two factors: emissions of CO_2 and other GHGs which are considered as an input into the aggregate production function. Environmental damages that are associated with the global stock of CO_2 and GHGs, which

tributant to the global warming phenomenon. The first reason is that CO_2 emissions is the most important of all the other GHGs such as methane, nitrous oxides etc in terms of percentage contribution in the global warming phenomenon. The second reason has to do with the avaliability of data on CO_2 emissions for those two large groups of countries.

[15] The Stern Report scenario corresponds to 2.5% annual increase of CO_2 emissions.

accumulate globally and cause global warming and climate change[16].

Capital accumulation in our stylized economy is described by using the standard Solow model. We assume that exogenous technical change of labour augmenting type and technical change associated with emissions are present. The production function we use is of the form:

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

where K is physical capital, H is human capital, AL is effective labour with L being labor in physical units, A reflecting labor augmenting technical change[17] and 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[18]. Using the Cobb-Douglas assumption, the production function (1) becomes:

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

Assuming the existence of constant returns to scale: $a_1 + a_2 + a_3 + a_4 = 1$, and expressing output in per worker terms, where $y = \frac{Y}{L}, k = \frac{K}{L}$, $z = \frac{Z}{L}$and $h = \frac{H}{L}$, we obtain:

$$\begin{aligned}
\frac{Y}{L} &= \left(\frac{K}{L}\right)^{a_1} \left(\frac{H}{L}\right)^{a_2} \left(\frac{AL}{L}\right)^{a_3} \left(\frac{BZ}{L}\right)^{a_4}, \\
y &= \left(e^{gt}\right)^{a_3} \left(e^{bt} z\right)^{a_4} k^{a_1} h^{a_2}, \\
y &= e^{(ga_3 + a_4 b)t} k^{a_1} h^{a_2} z^{a_4} \ , \ ga_3 + a_4 b = \lambda \\
y &= e^{\lambda t} k^{a_1} h^{a_2} z^{a_4}
\end{aligned}$$

Capital accumulation in per worker terms, assuming that the two capital goods (produced and human) depreciate at the same constant rate[19] is given by:

$$\dot{k} + \dot{h} = sy - (\eta + \delta)(k + h) \tag{2}$$

Defining $k = \hat{k}e^{\xi t}$, $h = \hat{h}e^{\xi t}$, and $z = \hat{z}e^{\xi t}$ in efficiency units we have:

$$\dot{k} = \dot{\hat{k}}e^{\xi t} + \xi\hat{k}e^{\xi t}, \ \dot{h} = \dot{\hat{h}}e^{\xi t} + \xi\hat{h}e^{\xi t} \text{ and } \dot{z} = \dot{\hat{z}}e^{\xi t} + \xi\hat{z}e^{\xi t} \tag{3}$$

Substituting $\dot{k}$ and $\dot{h}$ in (2) we obtain:

$$\dot{\hat{k}}_t e^{\xi t} + \xi\hat{k}e^{\xi t} + \dot{\hat{h}}_t e^{\xi t} + \xi\hat{h}e^{\xi t} = se^{\lambda t}(\hat{k}_t e^{\xi t})^{a_1} (\hat{h}_t e^{\xi t})^{a_2} \left(\hat{z}e^{\xi t}\right)^{a_4} - (\eta + \delta)(\hat{k}_t e^{\xi t} + \hat{h}_t e^{\xi t})$$

[16] CO_2 emissions is the basic contributor to the global warming phenomenon and thus is used in this paper as the fundamental environmental factor in the production function.

[17] $A(t)$: *the level of* labor augmented technical change *is defined as* $A_0 e^{gt}$.

[18] $B(t) = B_0 e^{bt}$. We normalize the initial level of emission augmented technical change, by setting $B_0 = 1$ assuming that each of the groups of the countries we examine started at the beginning of our data period (1965) approximately at the same level of emissions augmenting technical change.

[19] For this assumption see Barro and Sala-i-Martin, (2004).

dividing with $e^{\xi t}$ we obtain:

$$\dot{\hat{k}}_t + \dot{\hat{h}}_t = \frac{se^{\lambda t}\hat{k}_t^{a_1}e^{\xi t a_1}\hat{h}_t^{a_2}e^{a_2\xi t}z_t^{a_4 a_2}e^{a_4\xi t}}{e^{\xi t}} - (\eta+\delta+\xi)(\hat{k}_t+\hat{h}_t)$$

$$\dot{\hat{k}}_t + \dot{\hat{h}} = se^{(\lambda-\xi+a_1\xi+a_2\xi)t}\hat{k}_t^{a_1}\hat{h}_t^{a_2}\hat{z}_t^{a_4} - (\eta+\delta+\xi)(\hat{k}_t+\hat{h}_t) \tag{4}$$

Setting $\lambda - \xi + a_1\xi + a_2\xi = 0$ so that (4) becomes time autonomous we have $\xi = \frac{\lambda}{1-a_1-a_2} = \frac{ga_3+a_4b}{1-a_1-a_2}$, and

$$\dot{\hat{k}}_t + \dot{\hat{h}} = s\hat{k}_t^{a_1}\hat{h}_t^{a_2}\hat{z}^{a_4} - (\eta+\delta+\xi)(\hat{k}_t+\hat{h}_t) \tag{5}$$

Following (Barro and Sala-i-Martin, 1995) we assume that savings are allocated between physical and human capital so that the two marginal products of capital are equal if we use both forms of investment. For this to be achieved, the following conditions should be satisfied:

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

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

$$\hat{h}_t = \frac{a_2}{a_1}\hat{k}_t,\ \dot{\hat{h}}_t = \frac{a_2}{a_1}\dot{\hat{k}}_t$$

then (5) becomes:

$$\dot{\hat{k}}_t + \frac{a_2}{a_1}\dot{\hat{k}}_t = s\hat{k}^{a_1}\left(\frac{a_2}{a_1}\hat{k}_t\right)^{a_2}\hat{z}^{a_4} - (\eta+\delta+\xi)\left(\hat{k}_t\frac{a_2}{a_1}\hat{k}_t\right) \tag{6}$$

$$\left(1+\frac{a_2}{a_1}\right)\dot{\hat{k}}_t = s\hat{k}^{(a_1+a_2)}\hat{z}^{a_4}\left(\frac{a_2}{a_1}\right)^{a_2} - (\eta+\delta+\xi)\left(1+\frac{a_2}{a_1}\right)k \tag{7}$$

$$\dot{\hat{k}}_t = s\left(\frac{a_2^{a_2}a_1}{a_1^{a_2}(a_1+a_2)}\right)\hat{k}^{(a_1+a_2)}\hat{z}^{a_4} - (\eta+\delta+\xi)k \tag{8}$$

Setting: $\left(\frac{a_2^{a_2}a_1}{a_1^{a_2}(a_1+a_2)}\right) = \Psi$, where Ψ is a constant, we have:

$$\dot{\hat{k}}_t = s\Psi\hat{k}_t^{a_1+a_2}\hat{z}^{a_4} - (\eta+\delta+\xi)\hat{k}_t \tag{9}$$

Setting $a_1 + a_2 = \phi$, then we have:

$$\dot{\hat{k}}_t = s\Psi\hat{k}_t^{\phi}\hat{z}^{a_4} - (\eta+\delta+\xi)\hat{k}_t \tag{10}$$

where output in efficiency units is defined as:

$$\hat{y} = \Psi\hat{k}_t^{\phi}\hat{z}^{a_4}$$

(10) is a Bernoulli equation which can be solved in the following way:

Multiplying with $\hat{k}_t^{-\phi}$ we have:

$$\dot{\hat{k}}_t\hat{k}_t^{-\phi} = s\Psi\hat{k}_t^{\phi}\hat{k}_t^{-\phi}\hat{z}^{a_4} - (\eta+\delta+\xi)\,\hat{k}_t\hat{k}_t^{-\phi}$$

$$\dot{\hat{k}}_t\hat{k}_t^{-\phi} = s\Psi\hat{z}^{a_4} - (\eta+\delta+\xi)\,\hat{k}_t\hat{k}_t^{-\phi}$$

$$\dot{\hat{k}}_t\hat{k}_t^{-\phi} + (\eta+\delta+\xi)\,\hat{k}_t\hat{k}_t^{-\phi} = s\Psi\hat{z}^{a_4} \tag{11}$$

$$\dot{\hat{k}}_t\hat{k}_t^{-\phi} + (\eta+\delta+\xi)\,\hat{k}_t^{1-\phi} = s\Psi\hat{z}^{a_4}$$

Setting $\gamma = \hat{k}_t^{1-\phi}$, we have $\dot{\gamma} = (1-\phi)\dot{\hat{k}}_t\hat{k}_t^{-\phi}$. Then:

$$\dot{\gamma} + (\eta+\delta+\xi)\,\gamma(1-\phi) = (1-\phi)s\Psi\hat{z}^{a_4} \tag{12}$$

which is linear in γ and the solution is the following:

$$\gamma_t = \left(\gamma_o - \frac{s\Psi\hat{z}^{a_4}}{\eta+\delta+\xi}\right)e^{-(1-\phi)(\eta+\delta+\xi)t} + \frac{s\Psi\hat{z}^{a_4}}{\eta+\delta+\xi} \tag{13}$$

replacing $\gamma_t = \hat{k}_t^{1-\phi}$, we have:

$$\hat{k}_t = \left[\left(\hat{k}_o^{1-\phi} - \frac{s\Psi\hat{z}^{a_4}}{\eta+\delta+\xi}\right)e^{-(1-\phi)(\eta+\delta+\xi)t} + \frac{s\Psi\hat{z}^{a_4}}{\eta+\delta+\xi}\right]^{\frac{1}{1-\phi}}$$

$$\hat{k}_\tau = \left[\left(\hat{k}_t^{1-\phi} - \frac{s\Psi\hat{z}^{a_4}}{\eta+\delta+\xi}\right)e^{-(1-\phi)(\eta+\delta+\xi)(\tau-t)} + \frac{s\Psi\hat{z}^{a_4}}{\eta+\delta+\xi}\right]^{\frac{1}{1-\phi}}$$

by replacing $\hat{z} = ze^{-\xi\tau}$, the solution for the time path of the stock of capital is of the form:

$$\hat{k}_\tau = \left[\left(\hat{k}_t^{1-\phi} - \frac{s\Psi\left(z_te^{\xi\tau}\right)^{a_4}}{\eta+\delta}\right)e^{-(1-\phi)(\eta+\delta+\xi)(\tau-t)} + \frac{s\Psi\left(z_te^{\xi\tau}\right)^{a_4}}{\eta+\delta}\right]^{\frac{1}{1-\phi}}, \text{ for } \tau \geq t \tag{14}$$

Equation (14) express the time path of the physical capital stock in the economy as a function of the parameters of the economy and the time path of emissions per capita. We examine the way that the path of emissions might be determined in a market economy in the next section and the implication of the time paths of emissions on the economy's value function.

3 Value functions and policy implications under global warming

In this section we define the choice of emissions and the implied time path in a context of profit maximizing firms. Assume a representative competitive firm which solves the following profit maximization problem:

$$\begin{aligned} \max \Pi &= F(K, H, AL, BZ) - R_K K - R_H H - wL \\ & \text{subject to} \quad Z \leq \bar{Z} \end{aligned} \tag{15}$$

Positive marginal products for the inputs and profit maximization implies that $Z = \bar{Z}$. Where $\bar{Z}$ is an upper emissions limit for the representative firm. The upper bound on emissions could reflect technical constraints associated with production technologies or an emission limit determined exogenously by a regulator or an international agreement such as Kyoto. In this case aggregate emissions are constrained by the emission limit and emissions in per effective worker terms are defined as:

$$\hat{z} = \bar{Z}e^{-(\xi+\eta)t} = \frac{\bar{Z}}{L}e^{-\xi t} = \bar{z}e^{-\xi t} \tag{16}$$

where $\bar{Z}$ denotes the aggregate emission limit on CO_2 emissions and $\bar{z}$ the emission limit in per capita terms.

Using the standard Sollow assumption, where consumption is a fixed proportion of output we have that consumption in per effective worker terms is defined as:

$$\hat{c}_\tau = (1-s)\,\hat{y} \tag{17}$$

where $\hat{y} = ye^{-\xi t}$. Thus (17) will take the form:

$$\hat{c}_\tau = (1-s)\,\Psi \hat{k}_\tau^{\phi} \hat{z}_\tau^{a_4}$$

and by replacing $\hat{k}_\tau$ by (14) in the consumption function we have:

$$\begin{aligned} \hat{c}_\tau = (1-s)\,\Psi \Bigg[\Bigg(\hat{k}_t^{1-\phi} - \frac{s\Psi \left(\bar{z}_t e^{\xi\tau}\right)^{a_4}}{\eta+\delta} \Bigg) e^{-(1-\phi)(\eta+\delta+\xi)(\tau-t)} + \\ \frac{s\Psi \left(\bar{z}_t e^{\xi\tau}\right)^{a_4}}{\eta+\delta}^{\frac{\phi}{1-\phi}} \left(\bar{z}e^{-\xi t}\right)^{a_4} \Bigg] \end{aligned} \tag{18}$$

The general state of the environment is introduced into the model by the variable P, which is interpreted as the *stock* of CO_2 emissions which affects utility in a negative way. Then the utility function becomes a function of per capita consumption c_τ and total pollution P_τ and is assumed, as it is common in this type of analysis, to have the following separable specification:

$$U(c_\tau, P_\tau) = \frac{c_\tau^{1-\sigma}}{1-\sigma} - D(P_\tau) \text{ for } 0 \le \sigma < 1 \tag{19}$$

$$U(c_\tau, P_\tau) = \ln c_\tau - D(P_\tau) \text{ for } \sigma = 1 \tag{20}$$

In (19) σ is the elasticity of marginal utility, and P_τ is pollution stock which creates disutility. Therefore $D(P_\tau)$ can be interpreted as a damage function assumed strictly increasing and convex. We specify the damage function as $D(P_\tau) = \beta P_\tau^\gamma$ with $\beta > 0$ and $\gamma \ge 1$. Since the production structure is determined in per effective worker terms, we need to specify the utility function (19) in per effective worker terms. If we define consumption per effective worker as $\hat{c} = \frac{C}{AN}$, from the definition of per capita consumption we have:

$$\frac{C_\tau}{N_\tau} = c_\tau = \hat{c}_\tau A_t e^{g(\tau-t)}$$

then we have:

$$u(c_\tau) = \frac{1}{1-\sigma}\left(\hat{c}_\tau A_t e^{g(\tau-t)}\right)^{1-\sigma}$$

and the utility function (19) becomes:

$$U(c_\tau, P_\tau) = \frac{1}{1-\sigma}\left(\hat{c}_\tau A_t e^{g(\tau-t)}\right)^{1-\sigma} - \beta P_\tau^\gamma \tag{21}$$

We assume that the evolution of CO_2 stock, denoted by P_τ, is determined by a first order linear differential equation:

$$\dot{P}_\tau = \sum_{j=1}^{J} Z_i - mP_\tau \;\; , P(t) = P_t \tag{22}$$

where $\sum_{j=1}^{J} Z_j = Z^T$ is the sum of aggregate emissions from $j = 1, ..., J$ countries which are possibly constrained under an international agreement, with m reflecting exponential GHG's decay.

The solution of (22) is:

$$P_\tau = (P_t - \frac{Z^T}{m})e^{-m(\tau-t)} + \frac{Z^T}{m} \tag{23}$$

Then damages from CO_2 stock for country j can be determined as

$$D_j(P_\tau) = \beta_j \left[(P_t - \frac{Z^T}{m})e^{-m(\tau-t)} + \frac{Z^T}{m}\right]^{\gamma_j}$$

The utility flow in per effective worker terms for country j can be specified as:

$$U_j\left(\hat{k}_t, A_t, z, Z^T, P_t\right) = \frac{1}{1-\sigma}\left(\hat{c}_\tau A_t e^{g(\tau-t)}\right)_j^{1-\sigma} - \beta_j\left[(P_t - \frac{Z^T}{m})e^{-m(\tau-t)} + \frac{Z^T}{m}\right]^{\gamma_j} \tag{24}$$

The flow of total utility in the economy is $N_{j\tau}U_j(c_\tau, P_\tau)$, therefore the value function for the economy, using (24) becomes:[20]

$$V_{_jt} = \int_t^\infty e^{-\rho(\tau-t)} N_{_j\tau} U_j(\hat{k}_t, A_t, \hat{z}, Z^T, P_t)dt \ , \quad N_\tau = N_{jt}e^{n_j(\tau-t)} \tag{25}$$

$$V_{jt}\left(\hat{k}_t, N_t, A_t, , z, Z^T P_t\right) = \int_t^\infty e^{-(\rho-n_j)(\tau-t)} N_{jt}\left[\frac{1}{1-\sigma}\left(\hat{c}_\tau A_t e^{g(\tau-t)}\right)_j^{1-\sigma} - \beta_j\left((P_t - \frac{Z^T}{m})e^{-m(\tau-t)} + \frac{Z^T}{m}\right)^{\gamma_j}\right]dt \tag{26}$$

It should be noted that under an effective emission limit $\hat{z}$ is defined in terms of emission limit $\bar{z}$ through (16). We do not examined how countries have reached these emissions limits. They might have been determined through an agreements such as Kyoto's or limits might have been determined unilaterally. The key assumption is however that irrespective of how the limits have been set, they are not the outcome of an explicit optimization either at a national or at a global level, but, as it is probably more realistic, they are the outcome of a non-optimizing political process. In the above formulation we could distinguish between small and large countries. A small country will consider Z^T as a fixed exogenous parameter. On the other hand, a large country might recognize its contribution in total emissions. In this case, aggregate emissions for the large country l will be defined as:

$$Z^T = \bar{Z}_l + \sum_{j\neq l}\bar{Z} = \bar{Z}_l + Z^T_{-l} \tag{27}$$

If we write $\bar{Z}_l = \bar{z}_l e^{(\xi+\eta)t}$, then accounting prices for any country l at time t can be defined as:

$$p_{\hat{k}_{lt}} = \frac{\partial V_t}{\partial \hat{k}_{lt}},\ p_{N_{lt}} = \frac{\partial V_t}{\partial N_{lt}},\ p_{A_{lt}} = \frac{\partial V_t}{\partial A_{lt}},\ p_{P_{lt}} = \frac{\partial V_t}{\partial P_{lt}},\ p_{\bar{z}_{lt}} = \frac{\partial V_t}{\partial \bar{z}_{lt}},\ p_{\bar{Z}^T_{-lt}} = \frac{\partial V_t}{\partial \bar{Z}^T_{-lt}} \tag{28}$$

[20] A more complex structure would require, additional transition equations for say, natural resources (depletable or renewable), stocks of pollutants, human capital and so on. In this case the value function would depend on the current values of the stocks for these assets. The development of such a dynamic system, so that the value function can be defined in an operational way, is an area for future research.

It should be noted that there is an accounting price for the emission limit $\bar{z}_l$, which is formed by two effects. The effect of the emission limit on consumption through the production function as reflected in (19), and the effect of the emission limit on environmental damages, through aggregate emissions as reflected in the second term of (24). There is also an accounting price for the aggregate emissions of all other countries since these aggregate emissions affect environmental damages.

Since for any variable $\omega = \left(\hat{k}, \hat{z}\right)$ we have:

$$\hat{\omega} = \omega e^{-\xi t} = \frac{\Omega}{N} e^{-\xi t} \tag{29}$$

accounting prices in total and per capita terms are defined as:

$$p_{t\Omega_t} = \frac{\partial V_t}{\partial \hat{\omega}_t} \frac{\partial \hat{\omega}_t}{\partial \Omega_t} = \frac{e^{-\xi t}}{N_t} p_{t\hat{\omega}_t} \tag{30}$$

$$p_{t\omega_t} = \frac{\partial V_t}{\partial \hat{\omega}_t} \frac{\partial \hat{\omega}_t}{\partial \omega_t} = e^{-\xi t} p_{t\hat{\omega}_t} \tag{31}$$

4 A productive base sustainability criterion

In our stylized economy, a positive change in current social welfare can be considered as an indicator of productive-base sustainability for the country analyzed. In other words if:

$$\dot{V}_t = p_{K_t} \dot{K} + p_{N_t} \dot{N} + p_{A_t} \dot{A} + p_{\bar{Z}_t} \dot{\bar{Z}}_\tau + p_{P_t} \dot{P}_\tau \geq 0 \tag{32}$$

then the economy is currently productive base sustainable. More analytically, if the time derivative of the social welfare function is positive, this implies that CCSW is positive and that genuine investment is also positive,[21] without implying sustainability in individual utility terms, (ii) if the time derivative is negative, then genuine investment is negative[22]. p_{K_t}, p_{N_t}, p_{A_t}, $p_{\bar{Z}_t}$, p_{P_t} are the accounting prices for capital, population, technology, the emission limit and the pollution stock. $\dot{K}$, $\dot{N}$, $\dot{A}$, $\dot{\bar{Z}}_\tau$, $\dot{P}_\tau$ are the rates of change of capital, population, technological change, emission limit and the pollution stock respectively.

Dividing by Nk where $k = \frac{K}{N}$, using the fact that $\dot{k} = \frac{d\left(K/N\right)}{dt} = \frac{\dot{K}}{N} - \frac{\dot{N}}{N} k$ and that the accounting price for capital in physical terns is related to the accounting price of capital in per effective worker terms, by (30) we obtain:

[21] Evidence provided by the World Bank (2006) suggest that investments in produced capital, human capital, and governance, combined with saving efforts aimed at offsetting the depletion of natural resources, can lead to future welfare increases in developing countries.

[22] As suggested by the World Bank (2006, Ch. 3), negative genuine saving rates imply that total wealth is in decline and policies leading to persistently negative genuine savings are unsustainable.

$$S_t = \frac{\dot{V}_t}{N_t k_t} = \frac{p_{t\hat{k}_t}}{A_t N_t}\left(\frac{\dot{k}}{k} + \frac{\dot{N}}{N}\right) + p_{tN_t}\frac{\dot{N}}{N}\frac{1}{k_t} + p_{tA_t}\frac{\dot{A}}{A}\frac{A_t}{N_t k_t} + p_{\bar{Z}_t}\frac{\dot{\bar{Z}}_\tau}{Z}\frac{Z}{N_t k_t} + p_{P_t}\frac{\dot{P}_\tau}{P}\frac{P}{N_t k_t} \quad (33)$$

where S_t measures the change in the value of the economy per unit of produced capital stock at time t and could be interpreted as the rate of return on produced capital measured in terms of social welfare. By multiplying S_t by the current stock of capital we obtain a measure of current genuine investment. Using as before $\dot{A}/A = g$; $\dot{N}/N = n$; and denoting the rate of growth of capital per worker by $\dot{k}/k = v$; by $\frac{\dot{\bar{Z}}_\tau}{Z} = \chi$; the rate of growth of the flow emission limit with $\chi < 0$ indicating that environmental policy becomes gradually more stringent and $\chi > 0$ indicating that environmental policy is gradually becoming laxer; and with $\pi = \frac{\dot{P}_\tau}{P}$ the rate of change of the GHGs stock, we have that social welfare increases currently and thus development can be considered as currently sustainable in productive base terms if:

$$S_t = \frac{p_{t\hat{k}_t}}{A_t N_t}(v+n) + p_{tN_t} n \frac{1}{k_t} + p_{tA_t} g \frac{A_t}{N_t}\frac{1}{k_t} + p_{\bar{Z}_t}\chi\frac{Z}{N_t k_t} + p_{P_t}\pi\frac{P}{N_t k_t} \geq 0 \quad (34)$$

5 Empirical Estimations - Parameters and Results

Based on the descriptive growth model of section 2 and the methodology developed to determine whether an economy is currently productive base sustainable, positive change on social welfare or not, we define in this section the parameters used and present the numerical values. The table that follows defines the parameters. The values correspond to the period 1965-1990.

Parameters	*Values in tables*
v : Average growth of capital per worker	$(1,3)$
n : Average growth of population	$(1,3)$
β : Marginal damages from CO_2 stock	$(1,3)$
s : Average saving rate	$(1,3)$
χ : Average growth of CO_2 emissions	$(1,3)$
k : Average value of capital per worker	$(1,3)$
N : Average value of population per country	$(1,3)$
Z : Average of CO_2 emissions per country	$(1,3)$
■ : Constant of the production function	$(1,3)$
$\phi = a_1 + a_2$	$(2,4)$
a_3 : Production elasticity with respect to labor	$(2,4)$
a_4 : Production elasticity with respect to emissions	$(2,4)$
g : Rate of growth of labor augmenting technical change	$(2,4)$
b : Rate of growth of emissions augmenting technical change	$(2,4)$
δ : Depreciation rate	$(2,4)$
σ : Elasticity of marginal utility	$(2,4)$
$\lambda = ga_3 + ba_4$	$(2,4)$
ρ : Utility discount rate	$(2,4)$
π : Growth rate of total stock of CO_2	$(2,4)$
γ : Parameter of the damage function	$(2,4)$
■ $= \frac{\lambda}{1-a_1-a_2}$	$(2,4)$

a_1 and a_2 are the production elasticities with respect to physical and human capital. In the competitive context all elasticities can be interpreted as the corresponding input share in output. In the context of Barro's assumption about the equality of marginal products of physical and human capital, we can interpret ϕ as the sum of share of each of these two types of capital. For the case of *developed countries*: a_3 is the share of labor and a_4 is the share of emissions. For the case of *developing countries* a_3 is the share of emissions and a_4 does not exists.

Tables 1, 2, 3 and *4* that follow, present the parameter values used in our analysis for each one of the *23 developed* and the *21 developing* countries we analyze in order to estimate the productive base sustainability criterion (34). All the data from *tables 1, 3*, are estimated using the Penn World tables 5.6. The estimated parameters in *tables 2* and *4*, are taken from Tzouvelekas, Vouvaki and Xepapadeas, (2006)[23].

Table 1: Parameters for the group of the 23 *developed countries*

[23] Tzouvelekas, E., Vouvaki, D. and A. Xepapadeas, "Total Factor Productivity Growth and the Environment: A Case for Green Growth Accounting", FEEM working paper 42, 2006.

Countries	v	n	β
CANADA	0.032928687	0.021663857	0.00000000589025
U.S.A.	0.025689321	0.016860844	0.0000000170573
AUSTRIA	0.056128625	0.005204929	0.0000000112802
BELGIUM	0.033679182	0.006020976	0.0000000112802
DENMARK	0.032228406	0.009740526	0.0000000112802
FINLAND	0.038567052	0.007327035	0.0000000112802
FRANCE	0.041156021	0.008760808	0.0000000112802
GREECE	0.048409278	0.005288991	0.0000000112802
ITALY	0.038191952	0.004650733	0.0000000112802
LUXEMBOURG	0.024833593	0.00845968	0.0000000112802
PORTUGAL	0.048177233	0.009314411	0.0000000112802
SPAIN	0.059058156	0.007504434	0.0000000112802
SWEDEN	0.03556534	0.009562269	0.0000000112802
SWITZERLAND	0.033619931	0.007888075	0.00000000589025
U.K.	0.034014633	0.004932269	0.0000000112802
JAPAN	0.076563662	0.010002479	0.00000000589025
ICELAND	0.041646473	0.02103928	0.00000000589025
IRELAND	0.043979598	0.008039493	0.0000000112802
NETHERLANDS	0.030230736	0.013831165	0.0000000112802
NORWAY	0.007732509	0.014628489	0.00000000589025
AUSTRALIA	0.023857968	0.021364042	0.00000000589025
MEXICO	0.028233733	0.030730162	0.00000000589025
TURKEY	0.046517799	0.01948306	0.00000000589025

table 1 continued

Countries	s	χ
CANADA	0.192667465	−0.000268545
U.S.A.	0.154015995	−0.005307595
AUSTRIA	0.224252472	0.010731307
BELGIUM	0.237979369	−0.007877097
DENMARK	0.207586337	−0.009204111
FINLAND	0.233684447	0.017010918
FRANCE	0.198030225	−0.007721138
GREECE	0.167062284	0.051160436
ITALY	0.208762513	0.021453243
LUXEMBOURG	*0.208762513*	−0.015120024
PORTUGAL	0.202154111	0.04375945
SPAIN	0.218688333	0.034295707
SWEDEN	0.206691146	−0.02630012
SWITZERLAND	0.319314338	0.004782584
U.K.	0.158115522	−0.008363536
JAPAN	0.300260704	0.029049305
ICELAND	0.164227689	−0.008439755
IRELAND	0.201257546	0.020256859
NETHERLANDS	0.260411589	0.001596095
NORWAY	0.285949685	0.005501036
AUSTRALIA	0.200730732	0.011726163
MEXICO	0.197188633	0.024634313
TURKEY	0.201245619	0.044337772

table 1 continued

Countries	k	N	Z	■
CANADA	29053.44	23264538.46	34.7	0.972305717
U.S.A.	26868.12	222123115.4	43	1.110251982
AUSTRIA	22481.44	7513230.769	15.7	0.852257132
BELGIUM	28152.6	9769153.846	29.8	0.884707674
DENMARK	25440.36	5034653.846	21.9	0.801291883
FINLAND	31474.16	4758153.846	19.4	0.704514053
FRANCE	25789.96	53046269.23	17.9	0.932318299
GREECE	17145.92	9355846.154	12.3	0.610576308
ITALY	22957.64	55493192.31	15.1	0.919599527
LUXEMBOURG	37022.96	357807.6923	74.9	0.828567478
PORTUGAL	7720.64	9487769.231	5.7	0.640545578
SPAIN	16900.32	36152269.23	12.5	0.895747244
SWEDEN	27359.56	8204807.692	18	0.909050164
SWITZERLAND	53245.24	6344538.462	12.7	0.865843589
U.K.	15321.44	56133653.85	22.1	0.919075505
JAPAN	19857.68	112855269.2	11.7	0.639526001
ICELAND	13281.72	223307.6923	15.6	0.949797951
IRELAND	15612.68	3251692.308	18.5	0.723397077
NETHERLANDS	25850.72	13791192.31	24.9	0.996420422
NORWAY	41986.04	4021692.308	14.2	0.762167448
AUSTRALIA	29943.04	14228115.38	28.7	0.918414009
MEXICO	11906.36	63155307.69	9.5	0.804922725
TURKEY	5459.76	42756115.38	4	0.443093265

For *tables 1 - above-* and *3 - that follows-* the parameters were obtained as follows: the average of the saving rates s for the case of the *developed countries* were obtained from the National Accounts of OECD database and for the case of the *developing countries* were obtained from the Economics, Business, and the Environment — National Savings: Gross savings as a percent of GNI. In estimating the production function we used fixed effects estimation so Ψ was the sum of the coefficient of the production function and the fixed effects of the production function. The shares of capital, labor, emissions and the rate of growth of labor augmenting and emission's augmenting technical change were obtained from Tzouvelekas, Vouvaki and Xepapadeas, 2006[24]. β which is the marginal damages from CO_2 stock was estimated for the developed countries using Fankhauser and Tol (1997) who estimated damages from the doubling of CO_2 in different world regions. For the developing countries, marginal damages were obtained using Nordhaus (1998)[25].

Table 2: Common parameter values

Parameter	ϕ	a_3	a_4	g	b	ga_3	ba_4	δ
Value	0.325968	0.596	0.077	0.014	0.026	0.008	0.002	0.03

[24] Tzouvelekas, E., Vouvaki, D. and A. Xepapadeas, "Total Factor Productivity Growth and the Environment: A Case for Green Growth Accounting", FEEM working paper 42, 2006.

[25] W. D. Nordhaus, 1998, Revised Estimates of the Impacts of Climate Change.

σ	$\lambda = ga_3 + ba_4$	ρ	γ	$\blacksquare = \frac{\lambda}{1-a_1-a_2}$
0.5	0.010675682	0.03	1	0.015838539

For *tables 2 - above-* and *4* - that follows, the parameters were obtained as follows: the depreciation rate δ was the same for the case of developed and developing countries and was obtained from Mankiw et all., (1992). The elasticity of marginal utility σ was also the same for both cases and suggests that the equal distribution of income does not have a significant weight in the utility function. The utility discount rate ρ was taken 3%[26] and $\gamma = 1$ which implies a linear damage function.

The parameter values for the group of *developing countries* are summarized in table 3 that follows.

Table 3: Parameters for the group of the 21 *developing countries*

Countries	v	n	β
PERU	0.012155219	0.026573374	0.0000000907476
THAILAND	0.064312423	0.026938467	0.0000000529394
PARAGUAY	0.0599008	0.029792926	0.0000000907476
MOROCCO	0.01180978	0.030086627	0.0000000578675
DOMINICAN REP.	0.052249044	0.029116439	*0.0000000578675*
GUATEMALA	0.021661835	0.025445452	0.0000000907476
HONDURAS	0.016896959	0.031984921	0.0000000907476
JAMAICA	−0.00078736	0.021162102	*0.0000000907476*
BOLIVIA	0.030452654	0.021997488	0.0000000907476
COLOMBIA	0.02456555	0.025270989	0.0000000907476
ECUADOR	0.039715588	0.025793195	0.0000000907476
IRAN	0.069761428	0.034655315	0.0000000692038
SRILANKA	0.030501594	0.018220663	0.0000000529394
SYRIA	0.017400356	0.0300723	0.0000000692038
YUGOSLAVIA	0.050017192	0.008301377	*0.0000000692038*
INDIA	0.036262979	0.019425761	0.0000000529394
KENYA	−0.007093912	0.040524848	0.0000000578675
MADAGASCAR	0.007302069	0.020755864	0.0000000578675
MALAWI	0.056975768	0.025468426	0.0000000578675
SIERRALEONE	0.048099166	0.014407023	0.0000000578675
ZIMBABWE	−0.015083099	0.036904505	0.0000000578675

Table 3 continued

[26] The value of 3% has been used by a number of researchers for the estimation of marginal social costs of CO_2 emissions (see, for example, surveys by Fankhauser and Tol, 1997, Tol, 2005). The values of 1% and 2%, along with time declining rates, have also been used in these studies.

Countries	s	χ
PERU	0.1877	−0.002464966
THAILAND	0.2777297297	0.075204219
PARAGUAY	0.1564102564	0.026822542
MOROCCO	0.2085714286	0.038209517
DOMINICAN REP.	0.1932432432	0.043170423
GUATEMALA	0.11885	0.012405097
HONDURAS	0.1550263158	0.017557974
JAMAICA	0.1973	0.017935637
BOLIVIA	0.1459714286	0.029362691
COLOMBIA	0.1784285714	0.010349838
ECUADOR	0.145425	0.05290342
IRAN	0.2933793103	0.020324961
SRILANKA	0.17465	−0.003297832
SYRIA	0.1774857143	0.061044875
YUGOSLAVIA	*0.1774857143*	0.03099768
INDIA	0.20095	0.036739344
KENYA	0.167225	−0.006222883
MADAGASCAR	0.5808333333	0.000359423
MALAWI	0.028	−0.003835103
SIERRALEONE	0.3292	−0.007724857
ZIMBABWE	0.1395789474	0.009521261

Table 3 continued

Countries	k	N	Z	$\blacksquare$
PERU	8648.615385	16312.34615	4.006080643	1.67630338
THAILAND	2866.730769	43799.96154	1.481421126	1.138801052
PARAGUAY	609.3076923	3010.769231	1.159184513	2.003815273
MOROCCO	2147.615385	18701.69231	2.280925304	1.487305361
DOMINICAN REP.	3836.615385	5408.153846	3.602092971	1.448813579
GUATEMALA	3298	6600.846154	1.701286795	2.021977514
HONDURAS	4286.192308	3492.384615	1.628043995	1.206198888
JAMAICA	4436.384615	2064.615385	7.004211969	0.984705172
BOLIVIA	5720.346154	5330.307692	2.174962904	1.303648667
COLOMBIA	10647.73077	25299.73077	4.818757212	1.438349103
ECUADOR	11560.53846	7690.538462	4.170708691	1.528243444
IRAN	8191.384615	37401.38462	11.59577103	1.966782581
SRILANKA	6924.961538	14127.73077	0.699531707	1.439297288
SYRIA	12150.84615	8287.5	7.553502822	1.993631799
YUGOSLAVIA	5422.346154	21765.53846	9.351693997	1.410042717
INDIA	1376.153846	656496.1154	1.269852887	0.740467897
KENYA	1130.076923	15803.53846	0.650252843	0.773179535
MADAGASCAR	1731.038462	8379.230769	0.258102064	1.05960691
MALAWI	365.7307692	5860.038462	0.200389063	0.735358606
SIERRALEONE	163.3076923	3162.692308	0.420699171	1.606222261
ZIMBABWE	5759.615385	6768.346154	3.451498869	0.569696794

Table 4: Common parameter values

Parameter	ϕ	$a_3 = s_z$	g	b	ga_2	ba_3
Value	0.095117	0.330547	0.00815	0.00405	0.004684	0.001339273

δ	σ	$\lambda = ga_2 + ba_3$	ϱ	γ	$\blacksquare = \frac{\lambda}{1-a_1-a_3}$
0.03	0.5	0.006023273	0.03	1	0.010487368

To determine (33) and (34), we also need values regarding the growth of CO_2 emissions and the growth of CO_2 stock. Treating the future growth of CO_2 emissions as a policy variable, the evolution of the CO_2 stock can be determined using (23) as:

$$P(t) = \frac{e^{xt} Z_0}{m + x} + e^{-mt}(P_0 - \frac{Z_0}{m + x}) \tag{35}$$

where m is the exponential pollution decay on emissions, x is the rate of growth of global CO_2 emissions, P_0 is the initial stock of CO_2 and Z_0 is the initial level of total CO_2 emissions globally. Regarding the parameters values, the initial stock of pollution from CO_2 emissions P_0 was 785.3 billion tons of CO_2 obtained from Guillerminet and Tol (2005) and the initial level of global total emissions (flow) Z_0 was 6.15 billion tons of CO_2 and was obtained from Guillerminet and Tol (2005). m, the exponential pollution decay on emissions taken at a value of 0.0083 from Reillly and Richards (1993). For the value of x we used three different scenaria regarding the evolution of CO_2 emissions. The first scenario, which was motivated by the Stern Report[27], follows the assumption that the global CO_2 emissions increase annualy by 2.5% or $x = 0.025$ per year. The second scenario is a scenario of constant global CO_2 emissions $x = 0$, that enabled us to extract helpful results for the impact of the environmental factor on productive base sustainability. The third scenario is based on an annual increase of global emissions per 0.5% or $x = 0.005$ per year. This is a completely arbitrary scenario chosen to check whether for low rates of growth of annual global CO_2 emissions, the productive base sustainability criterion changes sign.

6 Accounting Prices and Productive Base Sustainability for Developed and Developing Countries

This section presents the results of our empirical estimations which are based on our empirical model and the parameter values described in section 5. The accounting prices for the two groups of countries and the signs of the CCSW or the productive base sustainability criterion of the economies analyzed were obtained under the three different scenaria of global CO_2 emissions described in section 5.

When we follow scenario 1 ($x = 0.025$), the results indicate that both for *developed* and *developing* economies the accounting prices of capital (APK), CO_2 emissions ($A.PCO_2$), technological change (APG) are positive while the accounting prices of global emissions of CO_2 ($APGz$) and of the stock of CO_2 (APP) are negative. The signs of the accounting prices can be interpreted as following: When capital, CO_2 emissions and technological change increase per one unit, then the social welfare also increases. On the other hand, when global emissions and of the stock of CO_2 increases, this reduces social welfare and thus the sign of those accounting prices is negative. For the case of *scenario 1*, the sign of the current change on social welfare conditions $\left(\dot{V}\right)$ is *negative* which is something we expected due to the positive and high environmental degradation that the persistent increase of global annual CO_2 emissions create. Following *scenario 2* ($x = 0$), we observe that the results change significantly. As far as the signs of the accounting prices are concerned, we have the same pattern, but the CCSW criterion - $\left(\dot{V}\right)$ is now *positive* both for the case of *developed and developing* countries. This result confirms the hypothesis that the currently regarded as plausible path of global CO_2 emissions affects *negatively* productive base sustainability. Thus, our results indicate that by keeping emissions at a constant level, this environmental friendly but probably unrealistic scenario

[27] "Annual emissions are still rising. Emissions of carbon dioxide, which accounts for the largest share of greenhouse gases, grew at an average annual rate of around $2\frac{1}{2}\%$ between 1950 and 2000. In 2000, emissions of all greenhouse gases were around 42GtCO2e, increasing". The Stern Review, Part III: The Economics of Stabilisation, Chapter 7 pp. 169

would provide positive results for the CCSWC and imply current productive base sustainability. *Scenario 3* ($x = 0.005$), provides the same *positive values* for the accounting prices of capital, CO_2 emissions, and technological change, *negative values* for the accounting prices of global emissions, the stock of CO_2 and the productive base sustainability criterion[28]. This pattern confirms our initial hypothesis and observation that even with a very small percentage annual increase of CO_2 emissions, the results are not optimistic for productive base sustainability. Those results are an indication of the need for a strict management of global CO_2 emissions in order to avoid the erosion of the sustainability of the productive base of the economy that the global warming phenomenon creates.

7 Policy implications

As shown from the results of our empirical analysis, there are some basic parameters that affect the sign of the CCSW criterion. The basic one, is the accumulation of global CO_2 emissions in the atmosphere. We observe from our empirical analysis that when the annual growth of global CO_2 emissions increase from 0% to 0.5% or 2.5%, the current change in social welfare criterion changes sign and becomes negative ($\dot{V} < 0$). In particular, when we have 0% rate of growth of global emissions, then the growth of the stock of CO_2 emissions is negative and the growth of emissions of each country is zero. This means that the state of the environment has a positive impact on total social welfare and the criterion is positive both for the group of the developed and the developing economies. When we change the annual global emissions rate of growth to 0.5%, the growth of the stock of CO_2 is positive. This implies that the CO_2 accumulation has a negative impact on total social welfare and the criterion turns negative for developed and developing countries. When the global emissions rate of growth becomes 2.5%, the growth of the stock of CO_2 is also positive and the change in social welfare is "more negative" relative to the 0.5% CO_2 growth scenario. The global CO_2 emission's rate of growth can be adjusted by the use of specific policy tools such as emission limits ($\bar{Z}$) or emission taxes (τ). Those emission limits can be used on a country level so that global CO_2 emissions not to exceed a specific maximum level $Z^{global \max}$. Similar results can be obtained with the imposition of a tax as a policy tool. The Kyoto protocol can be regarded as an attempt to define $\bar{Z}$ and therefore the growth of emissions of the participating countries and globally. Our results suggests that in order to have productive base sustainability, the international agreements should set the limit of emission's growth very close to 0%.

From the results we obtained, we observe that there is a direct relationship between the growth of emissions of each country we analyze, the growth of global emissions, the growth of CO_2 stock and productive base sustainability criterion.

[28]For the case of Mexico (developed countries) in scenario 3, the result of the Current Changes on Social Welfare Conditions $\dot{V}$ is *positive* in contrast with all the other countries under analysis where the sign of $\dot{V}$ is negative for 0.5% global CO_2 emissions increasement.

The growth of emissions of each country affects the growth of global emissions which affects the growth of CO_2 stock. A result, a reduction of global CO_2 emissions could have two conflict impacts. The first is that reduced emissions will produce gains in terms of reduced CO_2 stock and this a positive effect for productive base sustainability. The second is that reduced emissions in a country may imply output reduction if other cleaner ways of production are not used. This implies reduced consumption and capital accumulation and a negative effect or productive base sustainability. Our results suggest that if emissions are kept constant the gains from the reduction of the globall CO_2 stock outweight any losses in output in an individual country, for all the countries examined and promotes productive base sustainability in all countries.

It is well known that output growth has been connected to the environment and sometimes the perception exists that environmental consciousness, care and environmental friendly politics can harm growth. Nevertheless, studies as those related to the environmental Kuznets curve and the related literature seem to provide evidence that tend to change this hypothesis and delink output growth and the environment in terms of reduction of total output in the case where environmental friendly policies are used. From our model, a parameter that can play an important role toward this de linking is the parameter b - the emission's augmenting technological change. The significance of this parameter is that it can be used as a potential policy tool to compensate for the negative impact that a reduction in emissions can have on growth. This can be obtained for example by subsidies for the use of cleaner technologies or by international R&D cooperation.

The second question that arises is whether a single country is able to change the sign of CSW and whether unilateral policies can have results and how significant those results will be in terms of productive base sustainability both for the country that takes the unilateral action of reducing CO_2 emissions and also for other countries that might benefit from the unilateral actions, since global CO_2 emissions might be reduced. This is a hard issue to be addressed due to the reason that when we deal with the greenhouse effect and climate change, we refer to global magnitudes. What we measure in these cases, is the contribution of all countries in total emissions. Unilateral policies can lead to the reduction of emissions in certain countries if these policies are applicable and effective. The case where the contribution of a group of countries in total emissions is positive (which is the realistic case) but there is one country with negative contribution in total emissions, the question that arises is whether this reduction can counterbalance the total result on current CSW. For example, if USA reduces its annual emissions of CO_2 and the rest of the world keeps increasing annual CO_2 emissions, the question is whether and how much productive base sustainability for each country will be affected. The significant parameter here is the percentage (%) contribution of a single country to total emissions. When we deal with U.S.A for instance, we know that this country has large importance in the global warming phenomenon as implied by the large contribution of U.S.A emissions on global emissions. If U.S.A for example followed policies that reduced it's CO_2 emissions yearly by 2%, this could promote productive base sustainability both in the U.S.A and in the rest of the world. This final result however depends also on the reaction of other countries. If the unilateral action triggers more emissions by other countries since they might expect that their increased emissions will be counterbalanced by the unilateral action, then the final result might be overall negative CSW. To further examine this question we measured the productive base sustainability criterion for the case of U.S.A using the following assumptions. The rate of growth of CO_2 emissions for U.S.A was negative and at the same time we assumed an annual global CO_2 emissions increase of 2.5% (for the other countries). The productive base sustainability criterion was negative. This experiment means that eventhough U.S.A, a country with a large contribution in the global warming phenomenon, could follow policies leading to a negative rate of growth of its own CO_2 emissions, this does not imply that the productive base sustainability criterion will be positive with a rate of growth of CO_2 emissions for the rest of the world increasing at 2.5% per year. This result suggests that the final result about productive base sustainability depends on the reaction of other countries. Our model could help at tracing these effects since basically this implies the incorporation of alternative paths for CO_2 emissions for different countries. The last test we run in order to verify that our main results were robust, was to choose a logarithmic utility function[29] instead of (24) where elasticity of marginal utility was $\sigma = 0.5$, assuming therefore $\sigma = 1$ we obtain results for the productive base sustainability criterion both in developed and in developing countries. The results we obtained using the logarithmic utility function are summarized as follows: When we follow scenario 1 ($x = 0.025$), with a global CO_2 emissions increasement per 2.5% and a logarithmic utility function, the productive base sustainability criterion becomes negative and the accounting prices of capital, technical change and emissions are positive while the accounting prices of global emissions and CO_2 stock are negative. If we follow scenario 2 where global CO_2 emissions is zero ($x = 0$), we observe that the results remain the same as before when we used (24) with $\sigma = 0.5$, both for developed and developing countries. More analytically, the productive base sustainability criterion is positive and the accounting prices of capital, technical change and emissions are positive while the accounting prices of global emissions and CO_2 stock are negative. Thus, the same conclusions and implications regarding productive base sustainability can be derived for the case where we use the same utility function that the Stern Report assumes.

8 Concluding Remarks

One of the basic variables that affect the current change on social welfare (CCSW) conditions is CO_2 emissions along with other GHG's emissions which are considered to be the basic contributors to the global warming phenomenon.

[29] Such a function has been extensively used in the Stern report, so our results about productive base sustainability could be interpreted in the context of the utility function assumptions of the Stern report.

This paper attempts to formulate a theoretical model to provide empirical results for the productive base sustainability of economies under global warming and can be characterized as a *productive base approach to sustainable development*. To achieve this, we tried to determine a criterion that measures the current change of the productive base of an economy by taking into account the environmental damage created from the global warming phenomenon. We considered a non optimizing growth framework and we derived results for the productive base sustainability of two large groups of countries, developed and developing. We applied the model in 23 developed and 21 developing countries by using three different scenaria of global CO_2 emissions' growth and we obtained results for the current productive base sustainability of each one of them.

The main empirical finding of the paper under two alternative utility function specifications is that when we follow the scenaria where global CO_2 emissions increase, then the productive base sustainability criterion is negative for almost all the countries under analysis. When global CO_2 emissions remain constant, the productive base sustainability criterion is positive both for the case of developed and for the case of developing countries. Our empirical findings confirm the perception that the intensification of the global warming phenomenon can erode the productive base sustainability of modern economies.

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