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Performance analysis for three pillars of sustainability

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Abstract: Gross domestic product (GDP) has come under criticism as the only objective countries' should pursue for societal well-being. In this paper we apply an innovative Data Envelopment Analysis (DEA) approach for including two other pillars including an environmental dimension, reduction of carbon dioxide (CO_2) emissions and a social dimension such as: increasing employment, and expanding healthcare and education expenditures. By linking together three DEA sub-technologies, we model a global technology which combines the objectives of the three pillars. Finally, by weighting each of them by different schemes, we demonstrate the practicality of our approach for policy tradeoffs governments can make among economic, environmental and social objectives.

Keywords: Three Pillars, Economic Efficiency, Environmental Efficiency, Social Efficiency, Data Envelopment Analysis, Multiple Frontiers.

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1. Introduction

Historically, the best method for accounting a nation's economic growth and well-being has been the use of either gross national product (GNP), GDP, or net national product (NNP). Since the outgrowth of environmentalism, there has been interest in measuring economic bads, i.e., pollution since including these types of bads in calculating a more accurate picture of economic activity. Leontief (1970) advocated that the inclusion of pollution and any other negative or positive effects should be included in the assessment of economic systems. Hamilton (1996) also argued for the necessity of including pollution as an adjustment for NNP. More generally, other arguments in the utility function such as environmental preservation and social benefits should be encompassed beyond simply consumption. Often considered the new economic measure beyond GDP to measure a populations' well-being, other factors have been identified including income, employment, good health care services, good education, and a clean environment (OECD, 2014). Whereas the previous studies employed traditional approaches for measuring economic activity, recent developments in the non-parametric, DEA focuses on including economic bads in the derivation of the production frontier (Seiford and Zhu, 2002; Färe and Grosskopf, 2004; Sahoo et al., 2011; Sueyoshi and Goto, 2011). Neglecting the commensurate production of economic bads will result in an upward bias of measuring performance. In the past, economic bads have been added on the input side. Whereas this approach may be an artifact for computational issues, pollution is clearly not an input to the production of a good. Therefore, pollution must be considered as an output and treated jointly with the production of goods. A large part of the related literature is devoted to consider pollution as a weakly disposable output jointly produced with the goods. However, this approach treats the problem of both productions in a unique production function which cannot model the complex relationships among goods, bads, and energy. For example, energy which is a good input in the production of goods but also a bad input as a main source of pollution.

More recently, a new modeling based on a by-production technology (Murty et al., 2012, Ray et al., 2017), considering two sub-technologies, one for the production of goods, another for the production of bads, allows to define relevant trade-offs among goods, bads and energy use. In this paper, we extend the idea of multiple sub-technologies to the three pillars. This approach can provide information that may be of interest to policy makers linking the overall production of energy while measuring the benefits of environmental improvement and the addition of jobs and improved health that have been missing in earlier studies.

Typically referred to as the three pillars of sustainability – economic, environmental, and social, there has some issues raised how to treat these three jointly. We use the three pillars approach using inputs into first deriving GDP growth with labor, capital, and energy as inputs. Next, we measure potential reductions in CO_2 as an output with energy as an input and as our proxy variable for potential environmental benefit that will be explained below. Finally, we examine how the social good pillar (employment, healthcare expenditures and education expenditures) are produced as outputs using labor stock as an input for employment and GDP as an input for healthcare and education expenditures. Whereas we use this approach at the macro level, our methodology can also be done at the micro level.

In this paper, our objective is to assess the jointness of these three pillars but rather than assigning weights a priori, we perform simulations wherein different weighting schemes can be employed based on policy agendas. For example, if mitigating climate change is a political priority, the environmental pillar should receive a higher weight as compared to maximizing GDP in already high income countries. In some of our results, an improvement of performance in the environmental pillar will lead to a decrease of GDP. The above example is typical of the degrowth model inspired by the work of Georgescu-Roegen (1977, 1979). More specifically, the concept of degrowth is that *overconsumption* lies at the root of environmental degradation and social inequalities. The degrowth concept fits with the notion of the three pillars of sustainability which include economic growth, environmental protection, and social well-being. All these trade-offs are analyzed in the proposed framework.

The rest of the paper unfolds as follow. In the next section we provide a recent literature review of the good modeling of bad outputs and the necessity to include social indicators in a global performance analysis. We next present our methodological approach followed by a description of the data we use in this study. Results from our analysis is presented and the paper concludes with a discussion and possible future research for sustainability.

2. Background

As stated in the introduction of this paper, there is a long history of justifying the inclusion of economic bads such as pollution in the economic production process. Leontief (1970) argued that even though conventional competitive markets include positive value, the inclusion of carbon-monoxide was excluded from the production process. He argues that this is incorrect since the production of carbon-monoxide exudes negative externalities and thereby should be included in the overall system of economic measurement. He further states that once the technical input-output combination in the production of goods have been determined, the inclusion of pollution can be analyzed as part of the economic process.

Recent studies on the effect of energy production and how this production has impacted the environment have been conducted following the prescient advice from Leontief (1970). Zhou, Ang, and Poh (2008) reviewed 100 papers on environmental and energy production studies and found that 25 included some type of assessment of the costs (either environmental or production). It was argued by the authors of the studies in this literature review that rather than using a strictly output-based DEA approach, a directional distance function or a hyperbolic efficiency approach is better suited for measuring the production of goods and bads both methodologically and theoretically. As part of Zhou et al.'s (2008) review, specific studies are pointed out here for the applicability to our study. Färe, Grosskopf, Noh, and Weber (2005) applied a quadratic directional output distance function to estimate the shadow prices of the pollutants by measuring the opportunity cost of reduced electricity (the good) by a one unit decrease in sulfur dioxide (the bad). Zhou et al. (2006) incorporated the slack values (i.e., the flat portion of the production frontier) to estimate the economic impact imposed by environmental regulations for 30 OECD countries between the years of 1998-2002. These authors found, whereas there was no opportunity cost imposed by environmental regulations, none of the countries were considered efficient in both technical efficiency and environmental improvement. Färe et al. (2007) estimated the joint production of goods (electricity) and bads (pollution) for 92 coal-powered plants operating in the US. They decomposed the relative importance of factors associated with the foregone production of electricity associated with abatement. They found some loss but it was limited. Zhang et al. (2008) estimated the eco-efficiency using DEA among Chinese provinces. There was some consistency in the provinces which met both efficiency and environmental improvement, but as these authors noted, Chinese officials in this centralized government were rewarded only on economic performance and not on environmental protection nor the social aspects associated with pollution (which the authors noted were not included in their study).

Bellenger and Herlihy (2009) employed the use of an output distance function as an alternative approach to environmental construction. They found little relation between environmental and economic indices and argue that it would be better to aggregate these two measures using existing data rather than imposing an a priori weighting system, with the former better at exhibiting actual performance and incentives of the countries' sustainability policies. Bosetti and Buchner (2009) aimed to address this weighting issue by using stimulated data on eleven global climate policy scenarios. They performed a sensitivity analysis and concluded that stringent climate policies outperformed policies that were less stringent if all sustainability factors are used in the DEA specification. However, these authors only considered environmental standards in their definition of sustainability. Kuosmanen and Kuosmanen (2009) echoed the sentiment of a sensitivity analysis by assessing sustainable value using the ratio of observed sustainability to the benchmark ala the production approach by Shephard (1953) and Farrell (1957) which is familiar to the DEA literature. The purpose of their paper was to refute the use of linear regression models in ascertaining the economic-environmental protection process. These authors applied the techniques of production efficiency to measure sustainability along the sustainability value (SV) approach. However, they were not able to include typical variables of labor and capital, nor were they able to include social well-being.

Antal (2014) argued that without systematic changes, green goals and full employment are incompatible. Without economic growth, unemployment will increase significantly with negative impacts on well-being. By comparing two correlations, Antal (2014) linked economic growth with environmental protection and lack of economic growth with unemployment. What Antal (2014) failed to do was link these concepts together, suggesting that for environmental impacts to be positive, they must be accompanied with a reduction on the dependence on economic growth to achieve lower unemployment.

In light of these studies, Murty, et al. (2012) added another approach in the assessment of economic bads in production referred to as the by-production technology. In the approach presented here, the by-production technology is represented as two distinct technologies – one used in the traditional sense of producing outputs from inputs and a second technology for the production of the bad or by-product. Taking the intersection of the two technologies, output and environmental efficiency can be decomposed. The benefit of this approach is that these authors surmise that the directional distance function and the hyperbolic function will still understate the degree of inefficiency. By taking the intersection of the two technologies – credit will be given to firms (or countries) who abate pollution by crediting them with increased environmental efficiency.

In this paper, we add a subset of the social welfare production process by including increased employment—health care expenditures and education expenditures. To summarize, we propose analyzing three production functions to address the issues presented above: energy production from an economic perspective; the effect that energy production has on the environment via decreasing the production of CO_2; and finally the positive social impacts of employment and potential positive social good improvements. In other words, we explicitly measure the three pillars of sustainability in the spirit of Georgescu-Roegen's definition of "degrowth" as it applies to the increased production of CO_2 as a proxy for the use of nonrenewable resources. In the next section, we describe the methodology employed to estimate these effects and how to analyze their joint production.

3. Methodology

We first define a production technology for each of the components of the three pillars. Then we link these three sub-technologies to define the overall three pillars technology. These links highlight the potential tradeoffs among the different objectives over the three dimensions. We use a standard microeconomic approach based on the definition of production sets from an axiomatic approach and on the use of a distance function to characterize theses sets (Shephard 1953).

3.1. Definition of the economic, environmental and social sub-technologies

We model the production technology for decision making units (DMUs) using N inputs (x) to produce M outputs (y). A general production possibility set can be defined as follows:

$$T = \left\{ (\mathbf{x}, \mathbf{y}) \in R_{+}^{N+M} : \mathbf{x} \text{ can produce } \mathbf{y} \right\} \quad (1)$$

For each sub-technology, DMUs could have specific inputs and outputs which interact with each other. In our model, the evaluation of economic performance is at an aggregated level for each country and uses capital stock (K), employment (L), and energy consumption (E) as inputs to produce gross domestic production (GDP). This defines the economic technology T_1. The energy input generates carbon emissions (CO_2) which are regarded as a bad output in the environmental evaluation (T_2). For evaluating social performance (T_3), labor stock (LS) is considered as the input in defining employment as the output. Furthermore, GDP is the main resource from which healthcare expenditure (HE) and education expenditure (EE) are made. Therefore, three sub-technologies for each of the component of the three pillars can be defined as follows:

$$\begin{aligned} T_1 &= \left\{ K,\ L \text{ and } E \text{ can produce } GDP \right\} \\ T_2 &= \left\{ E \text{ can produce } CO_2 \right\} \\ T_3 &= \left\{ LS \text{ can produce } L; GDP \text{ can produce } HE \text{ and } EE \right\} \end{aligned} \quad (2)$$

For estimation purposes, we employ a non-parametric framework to give an operational definition of the production sets and evaluate the distance to the frontiers of these sets. By assuming some basic assumptions such as free disposability and convexity and based on an observed sample of "I" countries, the economic technology can be defined as:

$$\begin{aligned} T_1 = \Bigg\{ &(K, L, E, GDP) \in R_{+},\ \sum_{i=1}^{I} \lambda_i GDP_i \geq GDP,\ \sum_{i=1}^{I} \lambda_i L_i \leq L,\ \sum_{i=1}^{I} \lambda_i K_i \leq K,\ \sum_{i=1}^{I} \lambda_i E_i \leq E \\ &\sum_{i=1}^{I} \lambda_i = 1,\ \lambda_i \geq 0\ \ \forall i = 1, \ldots, I \Bigg\} \end{aligned} \quad (3)$$

where $\boldsymbol{\lambda}$ is a vector of activity variables related to the economic sub-technology (Koopmans, 1951; Baumol, 1958). In T_1, we also assume variable returns to scale (VRS) to take into account size heterogeneity among countries. A constant returns to scale (CRS) assumption would lead to comparing small countries like New-Zealand to large countries like United States by scaling up or down. The VRS assumption allows for decreasing returns to scale which is presumably present in economics activities.

Similarly, we can define the environmental technology following Murty et al. (2012) as:

$$T_2 = \left\{ (E, CO_2) \in R_+,\ \sum_{i=1}^{I} \sigma_i CO_{2i} \leq CO_2,\ \sum_{i=1}^{I} \sigma_i E_i \geq E, \sigma_i \geq 0 \ \ \forall i = 1,...,I \right\} \quad (4)$$

where $\boldsymbol{\sigma}$ is the vector of activity variables related to the environmental sub-technology. Here, we assume that CO_2 is produced proportionately to the energy consumed thus constant returns to scale are introduced.

The social technology combines in itself two sub-technologies and is defined as follows:

$$T_3 = \left\{ \begin{array}{l} (LS, L, GDP, HE, EE) \in R_+, \\ \sum_{i=1}^{I} \mu_i L_i \geq L,\ \sum_{i=1}^{I} \mu_i LS_i = LS,\ \mu_i \geq 0 \ \ \forall i = 1,...,I; \\ \sum_{i=1}^{I} \zeta_i HE_i \geq HE,\ \sum_{i=1}^{I} \zeta_i EE_i \geq EE, \sum_{i=1}^{I} \zeta_i GDP_i \leq GDP,\ \zeta_i \geq 0 \ \ \forall i = 1,...,I \end{array} \right\} \quad (5)$$

The first sub-technology considers employment as part of the social pillar. From a given labor stock (LS), T_3 define the maximal level of feasible employment (L) in an economy. In our view, labor stock is exogenous in our analysis and cannot be reduced or increased. Therefore, we use equality on this constraint. The second sub-technology deals with healthcare and education expenditures. From a given level of generated GDP, T_3 defines the maximal level that healthcare and education expenditures can be increased. These two sub-technologies are independent and characterized by their own vector of activity variables, respectively $\boldsymbol{\mu}$ and $\boldsymbol{\zeta}$. Unlike the VRS assumption on GDP, the CRS assumption is used for the social technology. We consider that employment is proportionate to the labor stock and that healthcare and education expenditures are proportionate to GDP.

3.2 Definition of the three pillars technology

We now introduce the three pillars technology by combining the three sub-technologies on economic, environmental and social dimensions. While each independent sub-technology assumes exogenous inputs, we explicitly link them together. In our combined technology, only labor stock and capital stock are considered exogenous. Energy, CO_2, employment, as well as GDP, healthcare and education expenditures are considered as endogenous. Because links among the sub-technologies are explicitly made, tradeoffs among the three pillars will be possible.

Between the economic (T_1) and environmental (T_2) technologies, energy is a common factor. Energy is an input in the production of GDP but also produces CO_2, thus the level of energy used in T_1 should be equivalent to the consumption in T_2. The tradeoff is clear: while a higher level of energy use is needed to maximize GDP, a lower level is desired in order to minimize CO_2 emissions. In our three pillars technology, both objectives are considered and we introduce the explicit constraint $\sum_{i=1}^{I}\sigma_i E_i = \sum_{i=1}^{I}\lambda_i E_i$ that ensures the same energy consumption in both sub-technologies. This new constraint bridges the gap between economic and environmental performances.

In a similar vein, we link the economic frontier to the social technology by labor (L) and GDP. For social and economic points of view, employment can be both outcome and input cost, a high employment rate will make society fairer and better off, but it is an input in the production of GDP. We, therefore, introduce the link constraint $\sum_{i=1}^{I}\lambda_i L_i = \sum_{i=1}^{I}\mu_i L_i$, which makes sure that the level of employment is equivalent in the two sub-technologies. Here, the tradeoff is also clear: while we desire to maximize the level of employment from a social point of view, efficiency in economic activities minimizes the inefficient level of employment in the production of GDP. Similarly, GDP appears as the output in T_1 and is used in T_3 as an input for the production of healthcare and education via expenditures. We introduce the constraint $\sum_{i=1}^{I}\zeta_i GDP_i = \sum_{i=1}^{I}\lambda_i GDP_i$ in order to link these two sub-technologies. Finally, we can define our global three pillars technology as follows:

$$
\begin{aligned}
T_{3-pillars} = \Big\{ & (GDP, L, K, E, CO_2, LS, HE, EE) \in R_+ , \\
& \sum_{i=1}^{I}\lambda_i GDP_i \geq GDP, \sum_{i=1}^{I}\lambda_i K_i \leq K, \sum_{i=1}^{I}\lambda_i L_i \leq L, \sum_{i=1}^{I}\lambda_i E_i \leq E, \sum_{i=1}^{I}\lambda_i = 1, \lambda_i \geq 0 \forall i \\
& \sum_{i=1}^{I}\sigma_i E_i \geq E, \sum_{i=1}^{I}\sigma_i CO2_i \leq CO2, \sigma_i \geq 0 \forall i \\
& \sum_{i=1}^{I}\mu_i L_i \geq L, \sum_{i=1}^{I}\mu_i LS_i = LS, \mu_i \geq 0 \forall i \\
& \sum_{i=1}^{I}\zeta_i HE_i \geq HE, \sum_{i=1}^{I}\zeta_i EE_i \geq EE, \sum_{i=1}^{I}\zeta_i GDP_i \leq GDP, \zeta_i \geq 0 \forall i \\
& \sum_{i=1}^{I}\lambda_i L_i = \sum_{i=1}^{I}\mu_i L_i \\
& \sum_{i=1}^{I}\sigma_i E_i = \sum_{i=1}^{I}\lambda_i E_i \\
& \sum_{i=1}^{I}\zeta_i GDP_i = \sum_{i=1}^{I}\lambda_i\, GDP_i \Big\}
\end{aligned}
$$

(6)

3.3 Definition of the distance function and efficiency measurement

The three pillars technology defined in (6) serves as the basis for efficiency measurement. In order to compute the distance of any observed DMU to the frontier of this production set, we introduce a measurement tool defined as a distance function (Shephard, 1970; Chambers et al., 1996). Formally, the output directional distance function (Chambers et al., 1996) is defined by:

$$D_T(\mathbf{x,y;g}) = \sup\left\{ \delta \in \Re_+ : (\mathbf{x}, \mathbf{y} + \delta\mathbf{g}) \in T \right\} \quad (7)$$

where δ can be interpreted as the inefficiency score and measures the maximum possibility of increasing outputs. This increase is measured in terms of an output bundle given by the direction vector $\mathbf{g}$.

We adapt this approach to our context. First, while δ is a unique scalar in the definition given in (8), we introduce specific efficiency scores for each component of our three pillars technology as the vector: $\boldsymbol{\delta} = \left\{\delta_{GDP}, \delta_{CO_2}, \delta_L, \delta_{HE}, \delta_{EE}\right\}$. Second, while, in (7), δ is defined as non-negative ($\delta \in \Re_+$), we allow for the possibility of negative values ($\boldsymbol{\delta} \in \Re$). This is necessary to model the possible tradeoffs among the three pillars. As explained above, the minimization of the bad output CO_2 can lead to a decrease of GDP and hence a negative value of δ_{GDP}. This is particularly interesting because it allows us to consider scenarios of degrowth. Third, we chose, as the output bundle defining the direction vector $\mathbf{g}$, the observed outputs of evaluated DMUs. For a DMU 'i', we define: $\mathbf{g}^{i'} = \left\{GDP^{i'}, -CO_2^{i'}, L^{i'}, HE^{i'}, EE^{i'}\right\}$. The negative sign on CO_2 indicates that it is a bad output which must be minimized while other outputs are considered as good, hence positive. With this choice of the direction vector $\mathbf{g}$, the interpretation of efficiency scores $\boldsymbol{\delta}$ are straightforward as the feasible increase (or decrease for CO_2) as a percentage of the observed outputs. Fourth, we introduce different weighting schemes for each pillar: $\mathbf{w} = \left\{w_{ECO}, w_{ENV}, w_{SOC}\right\}$ in order to model different policy objectives for DMUs. In our empirical application, we will set weights such that priorities of each country can be put on economic, environment, social or any mix of the three pillars. Given these definitions, we arrive at the following three pillars distance function:

$$D_{3-pillars}(\mathbf{x},\mathbf{y};\mathbf{w},\mathbf{g}) = \sup\left\{ \mathbf{w\delta} \in \Re : (\mathbf{x},\mathbf{y}+\mathbf{\delta g}) \in T_{3-pillars} \right\} \quad (8)$$

The last step of our methodology is the estimation of efficiency scores. For a given DMU ‘i’, distance function in (8) can be computed by linear programming in a DEA framework.

$$\begin{aligned}
& D_{3-pillars}(\mathbf{x}^{i'},\mathbf{y}^{i'};\mathbf{w},\mathbf{g}^{i'}) = \\
& \max_{\delta,\lambda,\sigma,\mu,\zeta,\tilde{L},\tilde{E},GDP} \quad w_{ECO}\delta_{GDP}^{i'} + w_{ENV}\delta_{CO_2}^{i'} + w_{SOC}\frac{1}{3}(\delta_L^{i'} + \delta_{HE}^{i'} + \delta_{EE}^{i'}) \\
s.t. \; & \sum_{i=1}^{I} \lambda_i GDP_i \geq GDP^{i'} + \delta_{GDP}^{i'} GDP^{i'} \\
& \sum_{i=1}^{I} \lambda_i K_i \leq K^{i'} \\
& \sum_{i=1}^{I} \lambda_i L_i \leq \tilde{L} \\
& \sum_{i=1}^{I} \lambda_i E_i \leq \tilde{E} \\
& \sum_{i=1}^{I} \lambda_i = 1 \\
& \lambda_i \geq 0 \quad \forall i = 1,\ldots,I \\
& \sum_{i=1}^{I} \sigma_i CO_{2i} \leq CO_2^{i'} - \delta_{CO_2}^{i'} CO_2^{i'} \\
& \sum_{i=1}^{I} \sigma_i E_i \geq \tilde{E} \qquad \text{(LP1)} \\
& \sigma_i \geq 0 \quad \forall i = 1,\ldots,I
\end{aligned}$$

$$\sum_{i=1}^{I} \mu_i L_i \geq L^{i'} + \delta_L^{i'} L^{i'}$$

$$\sum_{i=1}^{I} \mu_i LS_i = LS^{i'}$$

$$\mu_i \geq 0 \quad \forall i = 1,\dots,I$$

$$\sum_{i=1}^{I} \zeta_i HE_i \geq HE^{i'} + \delta_{HE}^{i'} HE^{i'}$$

$$\sum_{i=1}^{I} \zeta_i EE_i \geq EE^{i'} + \delta_{EE}^{i'} EE^{i'}$$

$$\sum_{i=1}^{I} \zeta_i GDP_i \leq GDP$$

$$\zeta_i \geq 0 \quad \forall i = 1,\dots,I$$

$$\sum_{i=1}^{I} \mu_i L_i = \sum_{i=1}^{I} \lambda_i L_i$$

$$\sum_{i=1}^{I} \sigma_i E_i = \sum_{i=1}^{I} \lambda_i E_i$$

$$\sum_{i=1}^{I} \zeta_i GDP_i = \sum_{i=1}^{I} \lambda_i GDP_i$$

LP1 computes the efficiency score for each dimension of the three pillars. While it is further possible to introduce specific weights for labor, healthcare and education in the social dimension, we chose to weigh these dimensions equally. This restriction can be easily relaxed. As it appears clearly from LP1, only capital and labor stock ($K^{i'}$ and $LS^{i'}$) are exogenous. Labor, energy and GDP are part of the variables of LP1. At the optimal solution of LP1, we have the following equalities:

$$\begin{aligned} GDP &= GDP^{i'} + \delta_{GDP}^{i'} GDP^{i'} \\ \tilde{L} &= L^{i'} + \delta_L^{i'} L^{i'} \\ \tilde{E} &= \sum_{i=1}^{I} \lambda_i E_i = \sum_{i=1}^{I} \sigma_i E_i \end{aligned} \qquad (9)$$

Therefore, GDP, labor and energy are clearly endogenous in the model and their optimal level can be greater than, equal to or less than the levels of the evaluated DMU 'i' since efficiency scores are not restricted in sign: $\boldsymbol{\delta} \in \Re$. This flexibility is one of the main contribution of our three pillars model. For example, if we put more of weight on environment $\mathbf{w} = \{w_{ECO}, w_{ENV}, w_{SOC}\} = \{0,1,0\}$, the only objective is to reduce CO_2 emissions and the optimal level of energy would probably be less than the observed level for the evaluated DMU. This would lead to degrowth in GDP by the link introduced among the three sub-technologies. As another example, if all the weight is put on employment, the optimal level will surely be higher than the evaluated one and will probably lead to more GDP and more CO_2. A tradeoff between employment and environment would result. All tradeoffs among the three objectives are allowed by our model. Finally this application on empirical data will reveal the ultimate values of these tradeoffs for each country. As a summarizing remark, we could have also used simulated data as the evaluated DMU instead of using data from an observed DMU. Hence, the model can become a "normative" tool for simulating different scenarios and choosing the best policy in accordance with the social planner preferences.

4. Empirical results

4.1 Data

The data of capital stock, labor stock, GDP, and employment are from the AMECO database (European Commission, 2017); energy consumptions and carbon emissions are from the Headline Energy Data (International Energy Agency, 2016), and healthcare and education expenditures are from the World Development Indicators (World Bank, 2017). This dataset includes 21 OECD countries covering the years 2005-2012: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom (UK), and United States (US).

We construct a dataset for three sub-technologies: in the economic technology, net capital stock (billions Euros), employment (1000 persons), and energy consumption measured as kiloton of oil equivalent, KTOE [1] are used to produce GDP (billions Euros). In the environmental frontier, energy consumption can generate carbon emissions (measured in million tons). For the social pillar, employment is affected by labor stock (reported in 1000's of persons), and healthcare and education expenditures (are given in billions Euros) rely upon GDP. The capital stock, GDP, and healthcare and education expenditures are measured as at base year 2010 with purchasing power parity (PPP) s in billions of 2010 Euros.

In Table 1, we present partial productivity indicators used in sub-technologies on environment and social pillars. There appears to be variability in our data. For example, tons CO_2 per kg of energy shows variations from 1.31 for Sweden to 5.1 for Australia. The same is true for GDP ranging from 96.23€ for New Zealand to 11852.46€ for the United States.

Table 1 about here

Table 2 about here

The descriptive statistics presented in Table 2 demonstrates a wide variation with positive trends in all variables except for energy use and CO_2 emissions indicating that there is more conservation over this time period – which does not appear to negatively affect the other pillars of GDP and social good expenditures. It should also be noted that 1-L/LS is the unemployment rate. We note that Switzerland has over-employment which we attribute to the higher number of international employees at international organizations such as the World Health Organization and our labor stock variable is based on domestic workforces.

[1] All energy sources are considered included, oil, natural gas, coal, peat, oil shale, feedstock (such as corn) nuclear, and renewable resource as the total in the KTOE

Since there are infinite scenarios that could be examined and our model has many dimensions, (number of scenarios, number of pillars, number of countries, number of years), it would be impossible to present all feasible results for all the dimensions together. Hence, we made the choice to limit weights from all the weight on each pillar to an even split on two pillars and scenarios with heavier weights to a scenario wherein all pillars are equal in Table 3. We first present results at an aggregated level and then we highlight one or two dimension at a time.

Table 3 about here

Average efficiency change is presented in Table 4. We note that high values of average inefficiency for CO2, HE and EE in Table 4 can be explained by the initial variability of partial productivity indicators presented in Table 2. For example, we found a high possible increase of 83% in EE for scenario 3 but we also see in Table 2 to that the share of education expenditures in GDP goes from 3.61% to 8.13%. Therefore, if we observed in the initial data that some countries can spend more than twice than other countries, then an 83% increase in EE is realistic.

Table 4 about here

Recall that in Table 3, we present the 10 different weighting schemes used in assessing the three pillars. We note that these weighting schemes reflect different objectives in pursuing the desired outcomes and minimizing the bad outcome of CO_2. We provide these varying scenarios to demonstrate the idea presented in the background and methodology sections. Specifically, in some papers, social goods were underweighted and in others the environment was underweighted. In Table 4, we present our findings from these differing scenarios emphasizing that in this table the findings are for all the OECD countries in our sample for all years 2005-2012. It should be noted for the economic and social goods (GDP, L, HE, EE) a negative sign indicates a fall in this pillar. For the economic bad, CO_2, a positive sign indicates the amount this bad could be reduced, a negative sign reflects an increase in the CO_2 emissions.

When GDP is weighted by 100% (scenario 1), economic growth could increase by 18% coupled with an increase of CO_2 of 28%, an increase in employment of 7% with healthcare spending by 19% and education decreasing by 14%. When the environment is weighted by 100% (scenario 2), GDP would fall by 24% but, there would be a major improvement in the reduction of CO_2 by 66%. Employment, healthcare, and education expenditures would fall by 10%, 22% and 45% respectively. In the case when social welfare is weighted by 100% (scenario 3), GDP would grow (18%) as would employment (7%), and health and education would increase by 47% and 83% respectively. However, the environment would suffer by an increase of CO_2 by 28%.

In the case when the GDP and CO_2 are equally weighted at 50% each with no weighting on social welfare (scenario 4), there is some growth in GDP, 7%, but again, there is a large decline in the amount of CO_2 emissions (56%). There is a 5% growth in employment, while governments could expand spending on healthcare by 9% and decrease education expenditures by 22%.

Ignoring CO_2 by weighting GDP and social welfare each by 50% (scenario 5) demonstrates the same results as in the case when social welfare is weighted by 100% (scenario 3). In both cases, it is the tradeoff between these two objectives and the CO_2, with the latter increasing by 28%. Conversely, when CO_2 and social welfare are weighted at 50% each (scenario 6), GDP can grow by 7% but with a large potential reduction in emissions (56%), employment growth by 7% and with increases in health and education spending by 34 and 66% respectively%. Treating each of the pillars equally (scenario 7) we report an increase in GDP by 12%, a 48% reduction in CO_2, employment increases of 7% and higher expenditures in both health and education.

As in the case when CO_2 was weighted at 0% in scenarios 3 and 5, the lower weighting of CO_2 in scenarios 8 and 10, there is no reduction in emissions. It is only in the case of scenario 9, when the environment is weighted higher is there an opportunity to reduce emissions. But it should be noted that in scenario 9 there is only 2% growth in GDP.

For all specific OECD countries in our sample for all years (2005-2012), we present the results under scenario 7 wherein all the pillars are weighted equally. We present these results in Table 5.

Table 5 about here

Under scenario 7, Norway is the only country for which improvements in environmental and social dimensions lead to a small degrowth of 4%; for all other countries improving environmental and social pillars also lead to improve the economic pillar. There is a large variation in the amount of CO_2 that could be reduced from 18% for Italy to 71% in Poland. Employment increases are the greatest (more than 10%) for Spain, Portugal, France, Ireland and Belgium. Japan shows a negative value meaning that improvements in others dimensions can be made by reducing its level of employment. Increases in HE range from 1% for Denmark to 92% in Poland and EE could be increased the most, on average, indicating inefficient amount of expenditures on education in all the OECD countries in our sample except for Denmark. As discussed above, the wide range of variability in inefficiencies for HE and EE are related to the high degree variability we find in the initial data (Table 2). Finally, even if energy is not in the objective function of our three pillar model meaning that we do not seek to maximize or minimize energy use, we can compute its level for the optimal solution we derived. Interestingly, Finland, Belgium, Canada, Sweden and Norway can achieve maximal potential increases in the three pillars by reducing their energy consumption. On the contrary, countries such as Italy, Japan, Germany, Spain or Portugal require an increase in their level of energy consumption.

Since one of our main emphasis in this study is the reduction of CO_2 emissions, we examine the top five economies for scenario 7 as an illustration of changes over time.

Figure 1 about here

We note that the UK and the US are clustered well above the other three nations in this figure. France's CO_2 emissions trend demonstrated a decrease of 0.31% over time. Germany should a sharp increase than a steady decrease after 2008 until 2011 where there was first a sharp increase than a decrease. The economic crisis of 2008 seems only to have affected Germany in terms of a dramatic decrease in CO_2 emissions.

Japan is seen as being relatively efficient in the reduction of CO_2 emissions until 2010 when a steady increase of emissions increased by 8.13%. However, Japan also presents an interesting empirical finding in that after 2010's Fukishima disaster due to the earthquake and tsunami, Japan's nuclear energy was decreased and substituted other forms of energy use that increased CO_2 emissions.

In Table 6 we provide an example of results at a disaggregated level. We assess the performance of France and the US for the first and last years of our study period (2005 and 2012, respectively) under the three extreme scenarios 1, 2, 3, and the scenario 7

When weight is put on economic pillar, in scenario 1, France could expand GDP by between 26-29% for the first and last period. When reducing CO_2 is the only weighted objective (scenario 2) France can reduce CO_2 emissions by 57% and 62% respectively. Interestingly, this improvement in environmental performance is correlated with a strong decrease in the GDP level (-41% and -25%). The use of energy is also impacted (-33% and -36%). This is typical of a degrowth scenario. When weight is put on social pillar, increase in the employment level is about 12% to 15% while expenditures in healthcare and education can also be significantly expanded. The median scenario 7 leads to improvement in all dimensions.

Compared to France, in scenario 1, the US are efficient in the GDP dimension. In scenario 2, they could reduce the CO_2 by 69% in 2005 and 74% in 2012. Again, we can see here a degrowth scenario in 2005 in which the GDP fell by 18% as the employment (-14%) and expenditures on health (-18%) and education (-43%), and the same is true for 2012. Under scenario 3, the US are efficient in the labor dimension but could expand their expenses on healthcare and education. Under the more equally weighted scenario, the US are efficient on the GDP and employment dimensions but can still decrease significantly their CO_2 emissions the US.

Table 6 about here

5. Discussion and Summary

In 1809, Thomas Jefferson wrote "The care of human life and happiness – is the only legitimate object of good government". Corroborating this sentiment is the OECD that ranks the world's happiest countries that meet the objectives of GDP, jobs, education, health, and environmental quality (OECD, 2014). Given these objectives, we assessed how countries could meet these varying objectives and what are the possible tradeoffs. Typically, these obligations are referred to as the three pillars of sustainability – economic growth, environmental preservation, and social goods provision. However, there has been some issues raised how to treat these three jointly. In this paper, we adopted and expanded on the Murty et al. (2012) approach in which by-production technology is introduced. Our by-product assessment of economic growth and CO_2 emissions is based on two distinct but linked technologies. This is similar to the earlier argument made by Leontief (1970). We find that there is varying differences among scenarios and countries when optimal energy is compared with observed energy as a percentage. These findings indicate that some countries operate closer to the optimal energy use which not only does not lead to degrowth, but does lend optimism to other countries following these more efficient scenarios (and commensurate weighting schemes) and other countries' energy usage.

Moreover, we expand on the Murty et al. (2012) approach by adding the provision of social goods – employment growth, healthcare, and education. This is done because as Lehtonen (2004) wrote that the social dimension has been treated as the weakest and that the interaction between the environmental and social pillars have been largely ignored. Hence, we rectify this short-coming. We also include employment as part of the social welfare pillar.

Our findings also show that when GDP was weighted as zero, there was degrowth but growth in environmental improvement. Employment also fell when the environment was weighted as 100%. Therefore, degrowth may benefit the environment, but at the costs of more unemployment, and less expenditures on social goods. More difficult to achieve is the available increases in healthcare and education. When social pillars are more heavily weighted there is growth over time in the production of healthcare and education via higher expenditures. However, social well-being dipped as the economy suffered during the recession of 2008 but began to increase again after the "official end of the recession" in 2010. We also demonstrated that there is positive growth in our sustainability models over time in the figures presented above. This portends well that there is positive movement when the governments include other factors beyond GDP in establishing societal well-being. These findings are in line with those of Kuosmanen and Kuosmanen (2009) and Ang et al. (2011)

Some specific findings are worthy of note. We found that there is a wide range of findings by countries and that in general, GDP growth and increased employment go together, which is not surprising. Comparing France and the US, also demonstrated that GDP under VRS will lead to efficiency for the US as the largest OECD economy. But, this GDP does not automatically translate into increased social welfare expenditures especially in healthcare and education (both of which are increasingly market oriented in the US). Also expected, is that there exists a tradeoff between reduction of CO_2 emissions and GDP growth, corroborating the idea of degrowth. We also found that any positive weighting on the social welfare pillar increases the ability for governments to increase their spending on healthcare and education.

We also expanded on earlier methodological studies by moving beyond the typical distance functions (Färe et al., 2005; Zhang et al., 2008; Bellenger and Herlihy, 2009; and Kuosmanen and Kuosmanen, 2009) by including measures of labor (employment) and social welfare and by linking them all together to demonstrate the joint production under a variety of weighting schemes. While each independent sub-technology assumes exogenous inputs, we explicitly link them together. In our combined technology, only labor stock and capital stock are considered exogenous. Energy, CO_2, employment, as well as GDP, healthcare and education expenditures are considered as endogenous. Because links among the sub-technologies are explicitly made, tradeoffs among the three pillars are possible. Another extension is the possibility of negative values in efficiency scores. As shown in our results, the minimization of the bad output CO_2 can lead to a decrease of GDP which allows us to consider scenarios of degrowth. Finally, we introduce different weighting schemes for each pillar. While an application on empirical data reveals values of tradeoffs for each country, we could the model as a "normative" tool for simulating different scenarios and choosing the best policy in accordance with the social planner preferences. Our paper illustrates that it is possible for society to assess how best to produce necessary outputs, minimizing economic bads, and optimize well-being. Focusing on only one pillar, typically GDP, does not reconcile the full utility function of what is necessary for sustainability.

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Table 1 Descriptive Statistics of Inputs and Outputs

Variable	**Unit**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Trend**
Capital stock (K)	billions €	3626.20	5858.68	241.92	28355.11	1.50%
Employment (L)	1000 persons	20862.40	31829.79	1861.51	148295.00	0.06%
Energy (E)	KTOE	152.91	317.26	10.22	1576.04	-0.99%
GDP	billions €	1355.91	2407.90	96.23	11852.46	0.70%
CO_2	million tons	512.34	1133.72	29.65	5702.27	-1.54%
Labor stock (LS)	1000 persons	22422.58	34088.99	2052.00	157256.00	0.46%
Healthcare (HE)	billions €	101.19	182.97	6.32	953.22	3.31%
Education (EE)	billions €	67.61	124.14	5.57	618.53	1.42%

Table 2 Descriptive Statistics of partial productivity ratio by country – all years

	CO_2/E (KT)	L/LS (%)	HE/GDP (%)	EE/GDP (%)
Australia	5,10	95.09	5,99	4,95
Austria	2,54	95.66	8,10	5,45
Belgium	2,43	90.81	7,57	6,16
Canada	2,74	94.95	7,32	4,97
Denmark	3,22	95.71	8,95	8,13
Finland	2,24	92.41	6,53	6,28
France	2,12	90.35	8,46	5,54
Germany	3,39	92.82	8,18	4,60
Ireland	3,51	90.64	5,92	5,38
Italy	3,06	93.99	6,90	4,28
Japan	3,69	95.68	7,41	3,61
Netherlands	2,58	96.63	8,43	5,29
New Zealand	2,51	94.83	8,35	6,41
Norway	1,73	96.82	7,52	6,72
Poland	4,56	88.89	4,66	5,05
Portugal	2,74	88.82	6,75	5,07
Spain	3,12	85.36	6,58	4,50
Sweden	1,31	92.50	8,13	6,65
Switzerland	2,09	102.23	6,79	4,98
UK	3,56	93.49	7,40	5,41
US	3,55	93.10	7,53	5,24
Total sample	2,94	93.37	7,31	5,46

Table 3 Weight on each frontier for scenarios

Scenario	**Economic** **WECO**	**Environmental** **WENV**	**Social** **WSOC**
1	100%	0%	0%
2	0%	100%	0%
3	0%	0%	100%
4	50%	50%	0%
5	50%	0%	50%
6	0%	50%	50%
7	33%	33%	33%
8	67%	17%	17%
9	17%	67%	17%
10	17%	17%	67%

Table 4 Average inefficiency change for each scenario –OECD level, all years-

Scenario	**GDP**	**CO_2**	**L**	**HE**	**EE**	**Energy***
1	18%	-28%	7%	19%	-14%	+40%
2	-24%	66%	-10%	-22%	-45%	-28%
3	18%	-28%	7%	47%	83%	+40%
4	7%	56%	5%	9%	-22%	-6%
5	18%	-28%	7%	47%	83%	+40%
6	7%	56%	7%	34%	66%	-5%
7	12%	48%	7%	41%	74%	+12%
8	18%	34%	7%	47%	82%	+37%
9	2%	60%	3%	28%	57%	-15%
10	18%	34%	7%	47%	82%	+36%

*Energy reflects the variation of energy consumption in optimal level: (optimal energy-observed energy)/ observed energy.

Table 5 National inefficiency scores for scenario 7 – all years

Country	GDP	CO_2	L	HE	EE	Energy*
Australia	8%	69%	8%	62%	78%	+20%
Austria	32%	31%	7%	45%	96%	+34%
Belgium	3%	65%	13%	22%	36%	-34%
Canada	4%	67%	8%	27%	70%	-31%
Denmark	1%	57%	7%	1%	1%	+6%
Finland	16%	66%	11%	59%	51%	-41%
France	10%	33%	13%	16%	61%	+9%
Germany	24%	41%	9%	35%	119%	+54%
Ireland	3%	60%	13%	56%	57%	+9%
Italy	30%	18%	9%	69%	148%	+91%
Japan	33%	34%	-7%	61%	200%	+85%
Netherlands	10%	54%	6%	18%	70%	-10%
New Zealand	0%	48%	0%	9%	27%	0%
Norway	-4%	37%	6%	14%	16%	-17%
Poland	0%	71%	0%	92%	62%	0%
Portugal	34%	33%	15%	79%	116%	+41%
Spain	34%	37%	20%	83%	143%	+51%
Sweden	15%	28%	11%	28%	40%	-28%
Switzerland	2%	34%	0%	35%	67%	+6%
UK	0%	63%	0%	21%	50%	0%
US	0%	63%	0%	19%	55%	0%

*Energy reflects the variation of energy consumption in optimal level: (optimal energy-observed energy)/ observed energy.

Table 6 Performance analysis for the France and US for the first and last years of the study period

Country	Year	GDP	CO2	L	HE	EE	Energy*
France	2005						
	Scenario1	26%	-91%	12%	2%	-20%	+91%
	Scenario2	-41%	57%	-9%	-52%	-63%	-33%
	Scenario3	26%	-91%	12%	26%	85%	+91%
	Scenario7	8%	32%	12%	8%	59%	+6%
	2012						
	Scenario1	29%	-212%	15%	3%	-8%	+84%
	Scenario2	-25%	62%	-15%	-41%	-47%	-36%
	Scenario3	29%	-212%	15%	38%	98%	+84%
	Scenario7	12%	34%	15%	19%	71%	+11%
United States	2005						
	Scenario1	0%	40%	0%	-1%	-31%	0%
	Scenario2	-18%	69%	-14%	-18%	-43%	-20%
	Scenario3	0%	40%	0%	23%	59%	0%
	Scenario7	0%	61%	0%	23%	59%	0%
	2012						
	Scenario1	0%	0%	0%	-13%	-22%	0%
	Scenario2	-23%	74%	-18%	-33%	-40%	-25%
	Scenario3	0%	0%	0%	17%	69%	0%
	Scenario7	0%	65%	0%	17%	69%	0%

*Energy reflects the variation of energy consumption in optimal level: (optimal energy-observed energy)/ observed energy.

Figure1 Average CO_2 inefficiency score over time