Sustainability matters

Charles-Henri Dimaria

Sustainabilitymatters

Charles-Henri DiMaria[1]

STATEC Institut National de la Statistique et des Etudes Economiques, Luxembourg, and LEO Université d'Orléans

Tel: +352-247-88450

Fax: +352-26-20-37-26.

Charles-henri.dimaria@statec.etat.lu

Abstract: This document aims at bridging productivity measurement and weak sustainability in a specific data envelopment analysis framework that allows for negative output. In this framework countries use two inputs: capital and labour and seeks to maximize output and adjusted net saving. Adjustment net saving is seen as a sustainability indicator and then the productivity indicator computed can be understood as a sustainability productivity index. The higher the indicator is the higher productivity is and the probability of targeting sustainability.

Key words: *Weak sustainability, adjusted net savings, productivity, technical change, efficiency.*

Jel codes: Q56, O44, O47.

[1] STATEC Institut National de la Statistique et des Etudes Economiques, Luxembourg, and LEO Université d'Orléans, Charles-henri.dimaria@statec.etat.lu Tel: +352-247-88450 Fax: +352-26-20-37-26.

1 Introduction

Sustainability defined by Solow (1991) as “an obligation to conduct ourselves so that we leave to the future option or the capacity to be as well off as we are” has been a concern in economic growth theory for decades. The corner stone of most growth models is to analyse the path of the representative agent’s utility that measures its wellbeing. Then in this framework, “an economy is sustainable at some time t, if and only if the representative agent’s utility (wellbeing) U(t) then does not exceed the maximum level of utility which can be sustained forever from t onwards, given the capital stocks existing at t” (Pezzey, 2004)[2]. It could be unfortunate but, exception made of models where a poverty trap exists (see Azariadis and Stachurski, 2005, for a survey of such theories), most models has this property especially when technical progress is taken into consideration. This explains why productivity measurements have generated extensive researches following different methodology while it is considered as the engine of growth and consequently of increasing wellbeing.

However, the growing concern about greenhouse gas emissions and global warming has led researchers to developed green models of growth where unsustainability may occur even in the presence of technical progress. This literature can be broadly divided in two. The first strand includes models where natural resources are renewable and positively affect the wellbeing of agents, therefore paths that do not lead to complete depletion of natural resources are analysed and are considered sustainable (e.g. Beltratti and Chichilnisky, 1993). The second strand includes models where pollution is a by-product of production and/or consumption and adversely affects wellbeing of agents (see Xepapadeas, 2005). In this line, Brock and Taylor (2005) have developed a model where sustained economic growth and zero net pollution emissions coexist. And Stokey (1998) finds that continuing growth is possible with pollution abatement.

Therefore numerous studies measuring productivity have proposed frameworks that take into account pollution. Among the methodologies one may use, a very popular framework is data envelopment analysis. Recent examples of such approaches are Jeon and Sickels, 2004, Lo et al., 2005, Kumar, 2006, Zhou and Ang, 2008 and Lozano and Gutierez, 2008. In these studies pollution (mostly measured in terms of greenhouse gases emissions) is a by-product of production. Countries seek to simultaneously reach the highest level of GDP given the use of capital and labour inputs while reducing at most pollution. Noting that these analyses do not restrict to countries, Yu and Zongguo (2010) using a similar approach have assessed China’s urban environmental sustainability in considering three undesirable outputs that are major pollutants in measuring total factor productivity. These studies have in common to consider pollution as an undesirable positive output and then correct productivity considering that unsustainability results from greenhouse gas emissions. The goal is to maximize desirable output while minimizing undesirable output given resources. The approach in

[2] Incidentally, Ayong Le Kama (2001), recalls that the pioneer of optimal growth theory, Ramsey (1928), held that “discount later enjoyments in comparison with earlier ones [is] a practice which is ethically indefensible and arises merely from the weakness of imagination”.

this paper is to correct productivity taking into account sustainability rather than pollution-unsustainability.

In parallel to the measurement of productivity (considering pollution or not), contributions to the theory and measurement of sustainability have focused on the implications of imprudent use of natural resources and inefficient levels of environmental degradation for sustaining economic development (Atkinson and Hamilton, 2003). From the beginning of the nineties several authors have attempted to develop a practical indicator of sustainability e.g. Pearce and Atkinson (1993). Since the late nineties, the World Bank publishes a weak sustainability indicator that is the adjusted net saving indicator (ANS) or genuine savings for a broad range of countries. This statistic correspond to the sum of gross national saving and education expenditure minus consumption of fixed capital, depletion of natural resources and CO2 damages (and in some cases particulate pollution damages). Pezzey (2004) shows that if the ANS is negative then an economy is not sustainable, meaning that it is not insured that the agent's utility be forever non-declining. However, a positive ANS is not a sufficient condition for sustainability. But Hamilton and Hartwick (2005) show that making positive ANS an element of a policy rule can yield sustainability. Then it is legitimate to set high ANS as a policy goal to improve welfare in countries (Gnegne, 2009).

This document seeks to bridge productivity indexes and sustainability in a single indicator. The rationale is the following, in the Solow model of growth the long term steady state level or the long term stable growth path are determined negatively by depreciation of fixed capital (then capital consumption in ANS terminology) and positively by the saving rate. In 1996, Gali proposes an optimal growth model where multiple equilibria are possible depending on the choice of the saving rate. In this framework the policy intervention recommended, to avoid reaching low output equilibrium, is to subsidize investment. One could argue that another option could be to stimulate savings to reach the same goal and then to increase ANS. Varvarigos (2010), developed a model where pollution abatement may affect dynamics of the economy. If abatement costs are too high the country may be trapped and converges to a low steady state. Then, if not sufficient, it is likely that seeking high ANS cannot be detrimental to sustainability.

This document bridges the two frameworks in computing productivity indexes considering two desirable outputs GDP and ANS using data envelopment analysis. In other word it is assumed that the social benevolent planner aims at reaching productivity improvements (engine of long run growth) and a high adjusted saving rate such as the country reach the high output equilibrium while reducing to the extent possible the effect of pollution. High value of this new productivity index means that countries are able to achieve productivity gains while targeting sustainability.

The first section explains the framework. The following section presents results for a sample of European countries and the United States and decomposes the index in adjusted technical change and convergence effect. Here adjusted technical change translates improvement in the possibility of reaching higher sustainable productivity level given resources used in production processes. The last section concludes.

2 Framework

Despite the interest of the adjusted net saving indicator a drawback of this indicator for econometric analysis is that it could be negative. Then, in most case only levels of this indicator can be analysed (e.g. Stoever, 2012) and the familiar log-log formulation of productivity changes cannot be used (e.g. Reinhard et al., 2000). Similarly, in data envelopment analysis, most studies including pollution can deal only with strictly positive values of desirable and undesirable outputs (see Tyteca, 1997, for a review and references quoted in the introduction for more recent frameworks). The framework used in this article overcomes this problem in introducing ANS in the measurement of productivity growth as a desirable output that could have negative values. In other words, given resources used, countries seek to reach maximal output technically feasible and high genuine saving.

The method used is the measurement of productivity by data envelopment analysis introduced by Charneset. al (1978). This framework considers the case of multi-output and multi-input technologies and takes the form of a linear program. There are K inputs x (for example labour and capital) and I outputs y (for example GDP and ANS). In the case of countries, studies mainly restricts to two inputs. Basically the list of inputs restrict to capital, labour, energy, raw materials and services. The last three inputs are intermediate consumption and GDP is output minus intermediate consumption then all inputs are considered when the list restricts to GDP, capital and labour. Then a production possibility set at time t can be defined:

$$S_t = \{(x_t, y_t): x_t \; can\; produce \; y_t\}$$

This set represents all feasible input-output vectors. The boundary of this set is the maximum output that could be generated given inputs. The most desirable situation is to be on the frontier and the farer from the frontier the worst the situation is. This can be translated by a distance function defined as:

$$D^t(x_t, y_t) = sup\{\theta: (x_t, \theta y_t) \in S_t, \theta > 0\}$$

The distance function measures to what extent it is possible to expand production given the bundle of inputs and being still feasible.

The general formulation of the corresponding linear program is[3]:

$\max \Theta$

Subject to

$$\sum_{j=1}^{N} \Phi_j x_{kj} \leq x_{k0}, \forall k,$$

$$-\sum_{j=1}^{N} \Phi_j y_{ij} + \Theta y_{0i} \leq 0, \forall i,$$

$$\phi_j \geq 0.$$

[3] Data envelopment analysis has become a popular tool in measuring productivity, details about the formulation of linear programs to compute the Malmquist index and its decomposition can be found in various text books such as Ray (2004) and are then left out of this document.

In this formulation outputs are supposed to be positive. One may then compute a productivity index, that is positive, providing a performance analysis over a period of time as in Fare et al. (1992). This index takes the form of a Malmquist index first proposed by Caves et al. (1982):

$$M = \left[\frac{D_t^{t+1} D_{t+1}^{t+1}}{D_t^t D_{t+1}^t}\right]^{1/2}$$

The index is given by the ratio of distance functions obtained by comparing output to inputs in time t and t+1 using a given reference production possibility set. Here, the geometric averages of distances obtained using the production possibility set at time t and t+1 avoids the arbitrary choice of a reference production possibility set. Following Fare et al. (1992), the Malmquist index can be decomposed into adjusted technical change and efficiency change.

$$M = \left[\frac{D_t^{t+1} D_{t+1}^{t+1}}{D_t^t D_{t+1}^t}\right]^{1/2} = \left[\frac{D_{t+1}^{t+1}}{D_t^t}\right] \left[\frac{D_t^{t+1} D_t^t}{D_t^{t+1} D_{t+1}^{t+1}}\right]^{1/2}$$

The first term into brackets is efficiency change (convergence effect, getting closer to the frontier) while the second term is technical progress (ability to reach higher output given inputs). A value over unity of the Malmquist index indicates an improvement in productivity and a value below one is a regress. For the decomposition, a value below one for the technical progress indicates an increase. And for efficiency this term indicates a convergence towards best practices for values over unity and a divergence if the value is below one.

In this framework there are two outputs GDP and ANS. The problem is that ANS can be negative and then one cannot use this traditional approach. However, Silva Portela et al. (2004) propose an alternative data envelopment analysis framework where outputs can be positive and/or negative. The problem also takes the form of a linear program, but is based on the directional distance proposed by Chambers et al. (1996, 1998). The linear program is now:

$\max \Theta$

Subject to

$$\sum_{j=1}^{N} \Phi_j x_{kj} \le x_{k0} - \Theta R_{k0}, \forall k,$$

$$\sum_{j=1}^{N} \Phi_j y_{ij} \ge y_{i0} + \Theta R_{i0}, \forall i,$$

$$\sum_{j=1}^{N} \phi_j = 1,$$

$$\phi_j \ge 0.$$

With,

$$R_{i0} = max\{y_{ij}\} - y_{i0},$$

And

$$R_{k0} = x_{k0} - min\{x_{kj}\}.$$

Here there are just desirable outputs but one may be negative (adjusted net saving). In this framework, an efficiency measure is:

$$D_t^t = 1 - \Theta$$

The subscript t indicates that the efficiency index is computed for technology at time t and for the country being evaluated at time t. It is also possible to evaluate the performance of the country at time t given the technology available at time t+1 and conversely to look at the country situation at time t+1 given the technology evaluated at time t. And then one can compute from the linear programs a Malmquist index that can be decomposed into efficiency change and technical change.

One may argue that introducing the adjusted net saving is redundant as saving is the part of disposable income (that depends on GDP) not consumed. However, increases in productivity do not necessarily implies sustainability, it does not insure that greener technologies are used, it does not say anything about pollution abatement, it does not imply that the saving rate is such that the steady level is the higher one and / or is sufficient to escape a poverty trap. Then it is legitimate to introduce ANS as a desirable output to take into account for long term dynamics and pollution abatement.

Given the value of efficiency change and technical change, graphically it is possible to define six cases (see figure 1). In quadrant A where total factor productivity (TFP) is declining due to losses in efficiency (EFF) and technical change (TECH). The quadrant B is also characterized by losses in TFP with gains in EFF that are offset by losses in TECH. The quadrant C exhibits gains in TFP due to gains in EFF but these are lowered by losses in TECH. In quadrant D, most desirable situation, TFP is growing due to combined gains in EFF and TECH. The quadrant E includes countries with TFP gains due to TECH but these gains are lowered by losses in EFF. The last quadrant, F, TFP regresses because EFF losses are larger than TECH gains. A last interesting point is the intersection of the curve (defined by TECH=1/EFF) with lines going through 1. In this case there are no EFF gains or losses and no TECH gains or losses then no change in TFP, it is a steady state.

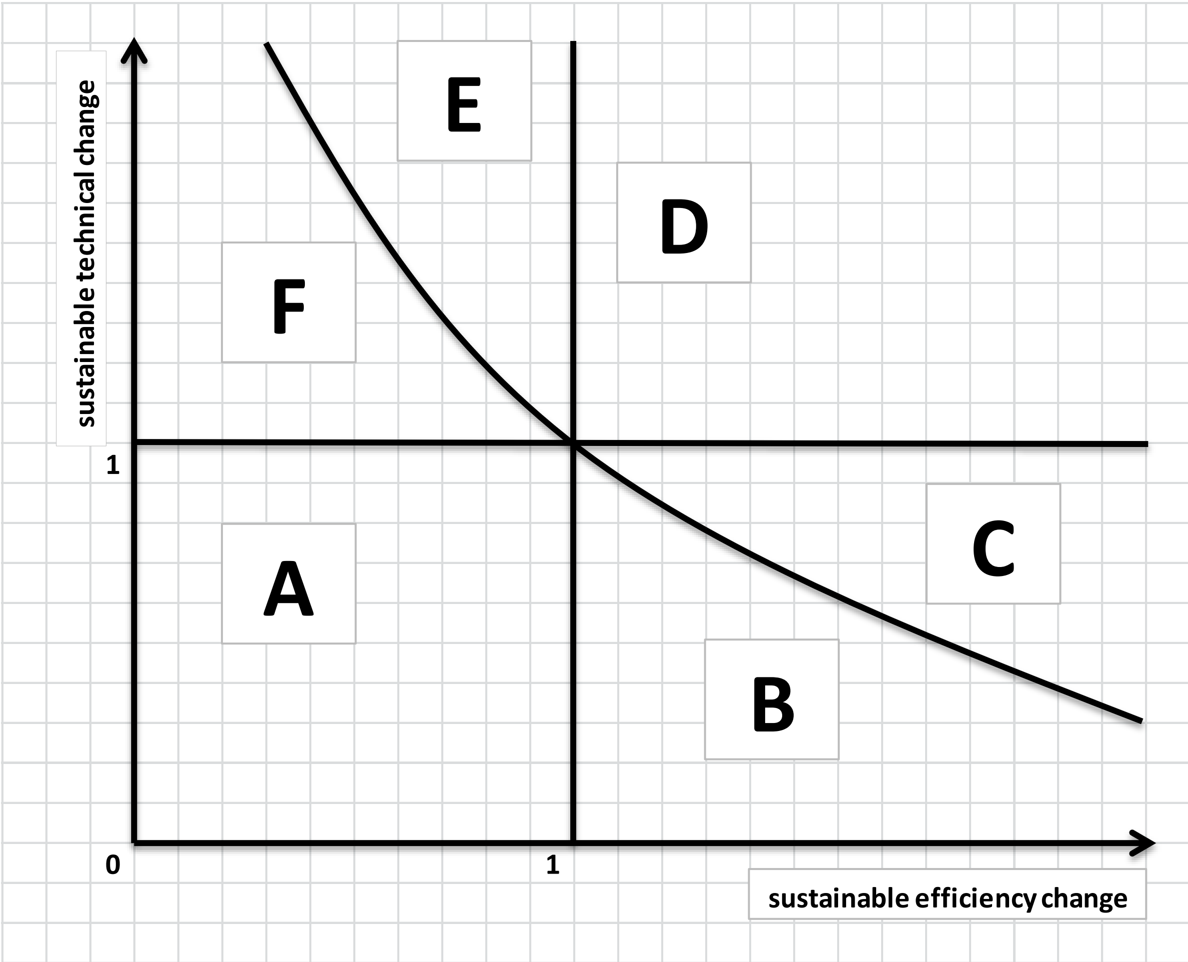


Fig. 1. Graphical representation of the Malmquist decomposition.

Productivity and sustainable productivity results

Data comes from the OECD for GDP, capital and employment. Everything is in constant term and expressed in terms of PPP for the sake of comparability. Adjusted net savings are computed by the World Bank. Data runs from 1995 to 2008 (last available year for ANS) and includes 15 European countries and the United States.

- Standard approach without considering ANS

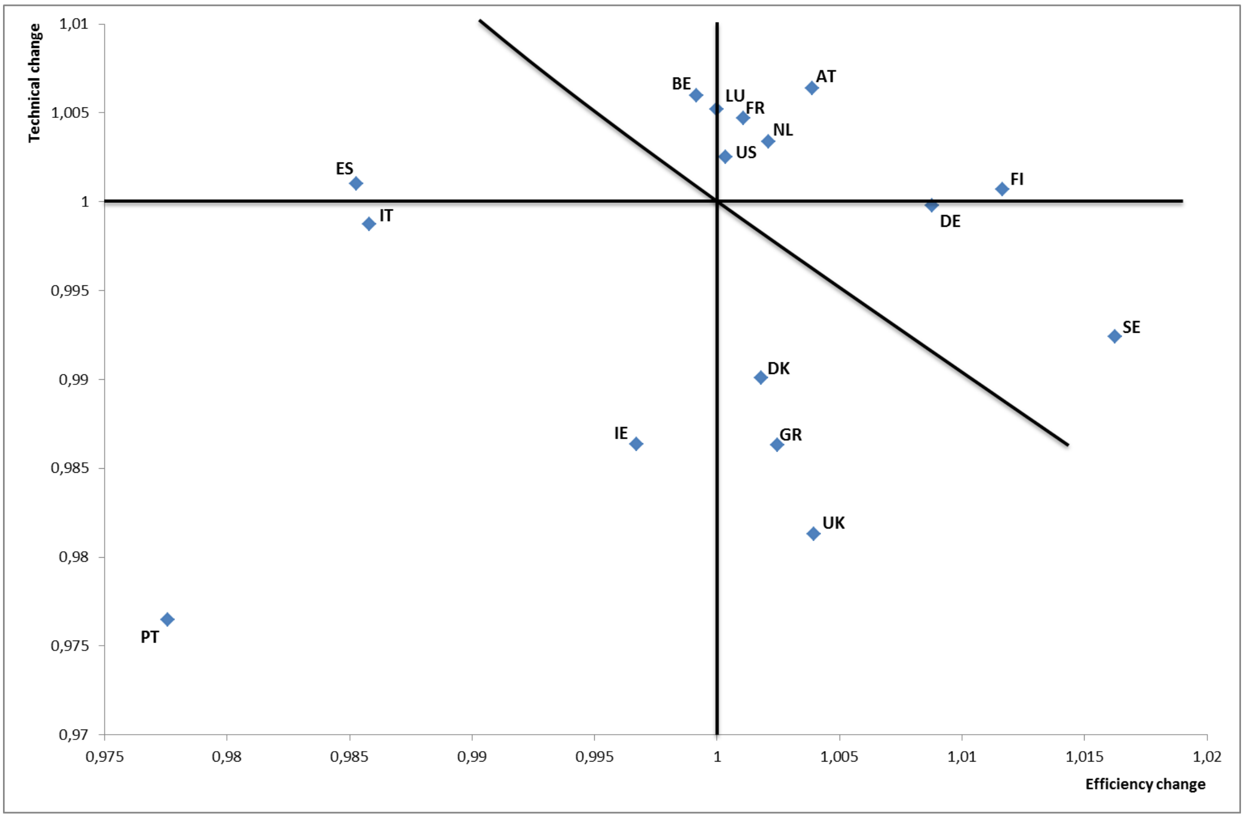
Looking at averages of efficiency change and technical change countries can be divided in 6 groups. The first one experiencing positive productivity change explained by positive technical change and positive efficiency change: Luxembourg, France, United States, Netherlands, Austria and Finland. At the opposite spectrum of situations: Portugal, Italy and Ireland with negative efficiency change and technical regress resulting in negative productivity change. In between four other groups, one including Denmark, Greece and United Kingdom where gains in efficiency change are offset by technical regress. A second group, including Spain, that is characterized by technical change but efficiency losses. The third cluster grouping Deutschland and Sweden, with productivity gains but lowered by technical regress. The last group is Belgium with positive productivity change lowered by efficiency losses[4].

Table 1.: geometric average of Malmquist, technical and efficiency change.

		Malmquist	Efficiency	Technical	Quadrant
Austria	AT	1,010	1,004	1,006	D
Belgium	BE	1,005	0,999	1,006	E
Deutschland	DE	1,009	1,009	1,000	C
Denmark	DK	0,992	1,002	0,990	B
Spain	ES	0,986	0,985	1,001	F
Finland	FI	1,012	1,012	1,001	D
France	FR	1,006	1,001	1,005	D
Greece	GR	0,989	1,002	0,986	B
Ireland	IE	0,983	0,997	0,986	A
Italy	IT	0,985	0,986	0,999	A
Luxembourg	LU	1,005	1,000	1,005	D
Netherlands	NL	1,006	1,002	1,003	D
Portugal	PT	0,955	0,978	0,976	A
Sweden	SE	1,009	1,016	0,992	C
United Kingdom	UK	0,985	1,004	0,981	B
United States	US	1,003	1,000	1,003	D

Fig. 2. Graphical representation of the Malmquist decomposition.

[4]Yearly figures are availble from the author upon request.



- Alternative approach including ANS

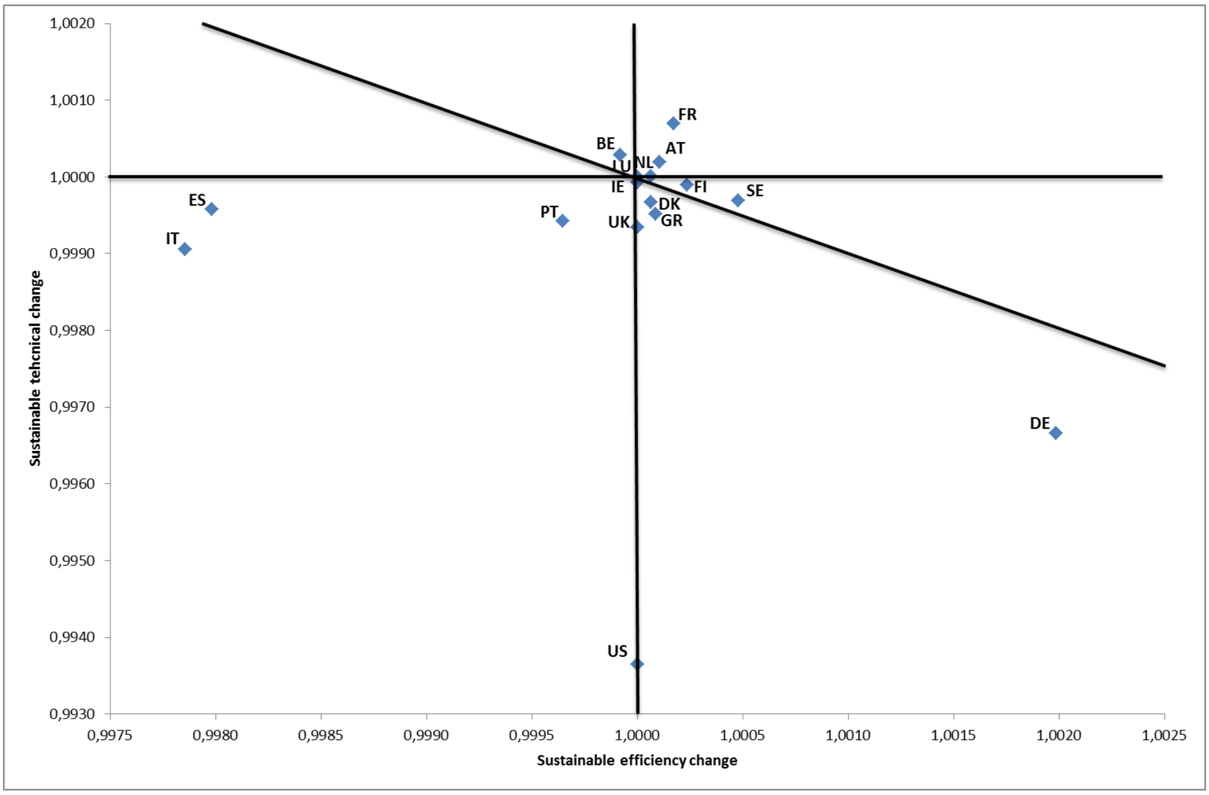
At a first glance there are no dramatically changes with the standard procedure. In most cases when productivity changes were positive (on average) the adjusted productivity remains positive and it is also the case when it was negative. However, three countries present opposite results from one framework to another, Luxembourg moves from a Malmquist index of 1.005 to 1.000, Deutschland moving from 1.009 to 0.998 and the United States with a change from 1.003 to 0.993. And, in contrast with the traditional approach averages of indexes are more clustered around 1.

Table 2.: geometric average of Malmquist, technical and efficiency change.

		Malmquist	Efficiency	Technical	Quadrant
Austria	AT	1,0003	1,0001	1,0002	D
Belgium	BE	1,0002	0,9999	1,0003	E
Deutschland	DE	0,9986	1,0020	0,9967	B
Denmark	DK	0,9997	1,0001	0,9997	B
Spain	ES	0,9976	0,9980	0,9996	A
Finland	FI	1,0001	1,0002	0,9999	C
France	FR	1,0009	1,0002	1,0007	D

Greece	GR	0,9996	1,0001	0,9995	B
Ireland	IE	0,9999	1,0000	0,9999	B
Italy	IT	0,9969	0,9979	0,9991	A
Luxembourg	LU	1,0000	1,0000	1,0000	D
Netherlands	NL	1,0001	1,0001	1,0000	D
Portugal	PT	0,9991	0,9996	0,9994	A
Sweden	SE	1,0002	1,0005	0,9997	C
United Kingdom	UK	0,9993	1,0000	0,9993	B
United States	US	0,9936	1,0000	0,9936	B

Fig. 3. Graphical representation of the Malmquist decomposition.

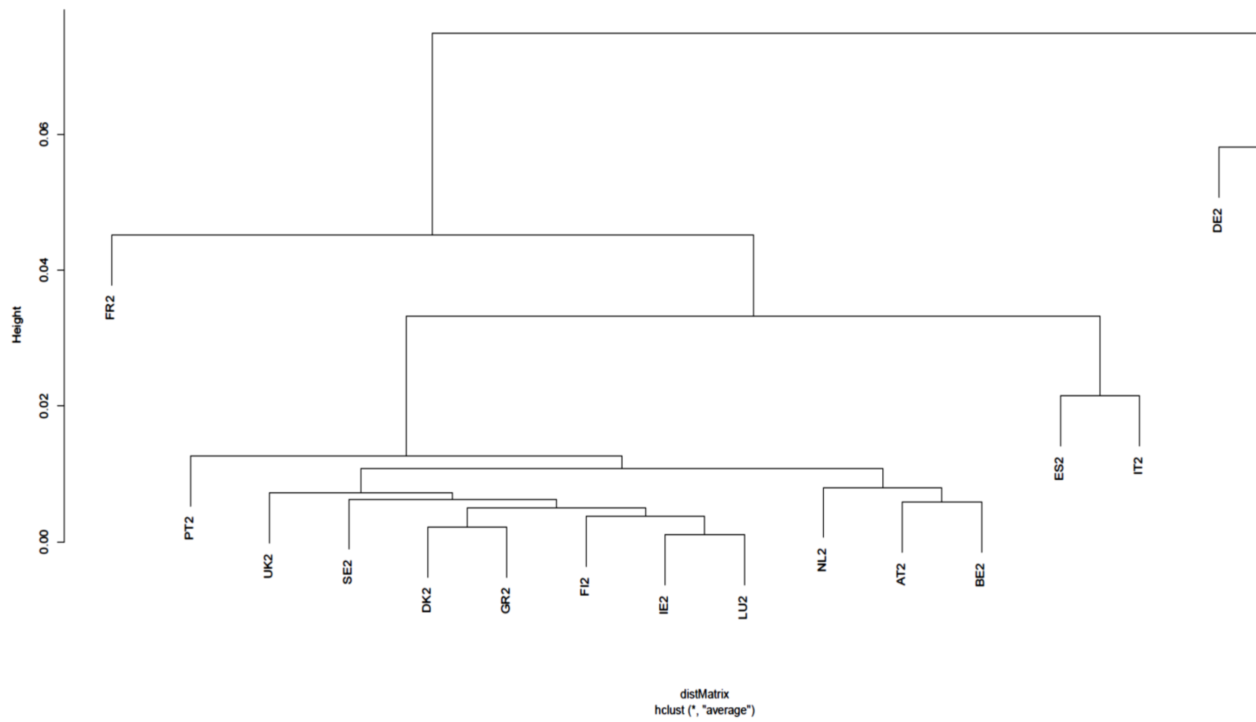


One may note that groups of countries are rather similar from one situation to another, however three countries have to be noticed: Portugal for which the situation seems to improve, the United States and Deutschland for which the situation seems to worsen.

If groups of countries exhibiting rather similar behaviour in terms of average sustainability productivity changes emerge from the graph, it could be interesting to explore if countries have similar behaviour across time. It is not unusual to compute correlations between indices of the different countries, however the drawback of this approach is that if two series are only proportional their correlation is 1 but the economic implication can be very different for countries. Another method to assess the degree of dependence of two series is cointegration, the problem here lies in the shortness of time series and then the lack of robustness of tests. In this document it is proposed to measure similarity of productivity series in using time series clustering. The approach is not new (see Liao, 2005, for a survey) and is very popular in various fields such as speech recognition. Basically, series are said to be similar if their distance are small and series are clustered given their distance. For example two series that are similar will have a distance of 0, they overlap. Series that are dissimilar have large distance. The first step is then to define a distance.

In 1979, Sakoe introduced the dynamic time warping distance. In general terms (details of the procedure can be found in Muller, 2007, and the basic algorithm is given in appendix) each observation of time series are analysed. At time t, the distance between this observation is computed with all observations of the other series (t,t+1,t+2,…). If there are T observations one has a matrix of T rows and T columns. The main diagonal is just the comparison of observations at the same time. Assume that the two series are increasing straight lines, if series are similar they overlap and the main diagonal is filled with 0 but all other cells are positive. If one look at the cell corresponding to the couple of observation (t,t+1) it measures the cost added if one substitutes the observation of the other time series at time t with the observation at time t+1. The algorithm seeks to find the number of substitutions that lead to the lower total cost. In other words, it is seek to what extent one has to rearrange observations to have similar time series. Again, for two similar time series it is just to keep the series as they are and to add the values on the first diagonal and then total cost is zero. Each time a substitution is made the cost is increased and the higher the total cost is the higher the dissimilarity is. Then a standard hierarchical cluster analysis is performed. At the first step all series belong to a specific cluster. Then two clusters are based on the smallest average distance between clusters. This step is repeated up to the point that there exists only one cluster including all series. This procedure can be represented by a tree, the more similar series are the earlier clusters are merged.

Fig. 4. Classification tree based on dynamic time warping.



If one compare the graph and the classification tree similarities emerge. Deutschland and the United States formed a separate cluster and belong to quadrant B far from other countries. Ireland and Luxembourg are grouped together at a very early stage and are almost situated on the stationary point (no technical change, no efficiency change). Spain and Italy are in a separate cluster and both are in quadrant A far from other countries.

Another point that might be of interest is to seek why a country presents a certain value for Malmquist indexes and subcomponents. Especially in this framework where there are two outputs and one is a composite index, indeed countries may have several ANS but for different reasons, low carbon emission and/or high education expenses. As explained in Simar and Wilson (2007) two steps procedures (the regression of Malmquist indexes over a set of explanatory variables) are not consistent. Emrouznejad and LatefAnouze (2010) suggest using classification and regression trees. Here, multivariate adaptive regression spline MARS are used (Friedman, 1991). Basically, the algorithm fits a sum of coefficient conditional to some basis function that are indicative or product of indicative function. For example,

$$y = \mu + \alpha I(x_1 > 0) + \beta I(x_1 > 0) I(x_2 > 0)$$

In such a case if no conditions are true then $y = \mu$, if the second condition is true then $y = \mu + \alpha$, and if all conditions are true then $y = \mu + \alpha + \beta$. See Moisen and Fescino (2002) to see the advantage of this approach over other tree methods. Each condition defines a knot that takes value 1 if it is true and 0 otherwise. Knots are chosen automatically in a forward stepwise manner taking for candidates all possible variables and all possible values. A knot is selected if it minimises the sum of squared residuals. Then a backward pruning procedure is applied to remove knots that contribute the least to the model (see Hastie and Tibshirani, 1996). Here an example is run on

Malmquistindexes pooled for the entire period, possible explanatory variables are all variables included in the computation of the modified Malmquist index[5].

With this sample knots are defined on the basis of these following variables: Carbon Dioxide Emissions (CO2), Expenditure on Education (EDE), Mineral Depletion (MID), Capital (K), GDP and consumption of fixed capital (CFC). The resulting equation is:

Malmquist =
1
- 0.064 *max(0,CO2 - 0.27)
+0.028 *max(0,4.8 - EDE) *max(0,CO2 - 0.27)
+0.077 *max(0,EDE - 4.8) *max(0,CO2 - 0.27)
- 0.023 *max(0,5.6 - EDE) *max(0,0.27 - CO2)
- 31 *max(0,MID - 0.053) *max(0, CO2 - 0.27)
- 3.1e-08 *max(0,CO2 - 0.27) * max(0,K - 2373674)
+ 1.5e-07 *max(0,5.6 - EDE) *max(0,0.27 - CO2) *max(0,1269089 - GDP)
- 5.2e-08 *max(0,5.6 - EDE) *max(0,0.27 - CO2) *max(0,2251507 - K)
- 5.3e-08 *max(0,CFC - 13) *max(0,5.6 - EDE) *max(0,0.27 - CO2) *max(0, 1269089 - GDP)
- 2.1e-08 *max(0,13 - CFC) *max(0,5.6 - EDE) *max(0,0.27 - CO2) *max(0, 1269089 - GDP)
+ 3.8e-08 *max(0,CFC -15) *max(0,5.6 - EDE) *max(0,0.27 - CO2) *max(0,2251507 - K)

This modelling is interesting as it could unearth complex nonlinear relationships. If one looks only at the first three lines of the equation: carbon dioxide emissions have a negative impact whenever they are over 0.27, but if the level of education expenditure is below 4.8 the effect is lowered and even more if expenditure are over 4.8 (a coefficient of 0.028 compared to 0.077). In passing, one may compute an R squared whose interpretation is similar to the case of linear regression. In this case the value is 0.6.

Conclusion

This document proposes a new computation of productivity changes taking account for weak sustainability. Rather than introducing pollutants as bad outputs, the adjusted net saving is introduced as a desirable output. As it could be negative, a specific DEA formulation has to be employed but when it is positive traditional DEA approaches can be used.

This indicator enriches the analyses going beyond the search for productivity gains. If all policy recommendations associated with previous productivity analysis remain valid, it opens new policy recommendations. For example, policies aiming at increasing human

---

[5]It is not argued here that it is the best set of exogenous variables many other contextual variables could have been added but it is not the purpose of this work to find any kind of "optimal set".

capital stock (see Heckman and Carneiro, 2003 for some policies) in order to increase adjusted net savings. In the same line, adjusted net savings can be increased in reducing emission of pollutant (see Bowers, 1997). In addition a graphical representation of the Malmquist decomposition is proposed. Last, to uncover similar productivity trajectories the use of dynamic time warping and cluster analysis is proposed. It is often interesting to evaluate factors behind the evolution of changes in this indicator and why countries belongs to a specific quadrant or cluster. One may propose two strategies, the first one advocated by Simar and Wilson (2007) is to use two stage regressions with bootstrap or to use classification and regression tree as proposed by Emrouznejad and LatefAnouze (2010). Incidentally, the second approach is much simpler to implement. In this document it was proposed to use multiple adaptive regression splines to uncover factor affecting the value of the adjusted Malmquist index.

Unfortunately this approach has also its drawbacks. The computation of the Malmquist indexes can encounter infeasible models as in Ray and Desli (1997) but the meta-frontier approach proposed by Silva Portelaet. al. (2004) should overcome this problem. The adjusted net saving is also criticised. First, in order to aggregate the various dimensions of this indicator monetary value have to be defined for pollution. The prize of the ton of carbon dioxide is fixed at the arbitrary value of 20 dollars (Stiglitz et al., 2009 and Dasgupta, 2007). In addition it assumes substitutability between physical, human and natural stocks and presupposes that the depletion of one or more of these stocks can be compensated by the increase of the others (Hamilton, 2007).

Appendix

Dynamic Time Warping algorithm:

Let $Y = \{y_t\}\ and\ X = \{x_t\}$ be to time series of length T:

1 create a square matrix of size T named C.
2 C(0,0)=0;
3 the first line and the first column is filled with large values (considered to be infinity) exception made of the first cell that is 0.
4 Do u=1 to T
5 Do v=1 to T
6 $cost = d(y_u, x_v)$ for example Euclidian distance.
7 C(u,v)=cost + min{C(u-1,v-1),C(u,v-1),C(u-1,v)}
8 End do v
9 End do u
10 total distance is C(T,T).

References

Atkinson, G., Hamilton, K.: Saving, growth and the resource curse hypothesis.World Dev. 31, 1793-1807 (2003).

Azariadis, C. and Stachurski, J.: Poverty Traps, Handbook of Economic Growth, in: Philippe Aghion and Steven Durlauf (ed.), Handbook of Economic Growth, edition 1, volume 1, chapter 5 Elsevier(2005).

Ayong Le Kama, A.D.: Sustainable growth, renewable resources and pollution, J. Econ.Dyn.Control. 25, 1911-1918 (2001).

Beltratti, A. and Chichilnisky, G.: Sustainable growth and the green golden rule, NBER Workp., 4430 (1993).

Bowers, J.: Sustainability and Environmental Economics, Prentice Hall (1997).

Brock, W. A., M.S. Taylor: Economic Growth and the Environment: A Review of Theory and Empirics, in Handbook of Economic Growth, 1B, edited by. P. Aghion and S. N. Durlauf, Elsevier: Amsterdam, 1749-1821 (2005).

Caves, D., Christiensen, L., Diewert, W.: The economic theory of index numbers and the measurement of input, output, and productivity, Econom., 50, 73-86 (1982).

Chambers, R.G., Chung, Y., Fare, R.: Benefit and distance functions, J. Econ.Theory, 70, 407-419 (1996).

Chambers, R.G., Chung, Y., Fare, R.: Profit, directional distance functions, and Nerlovian efficiency, J.Optim.Theory Appl., 98, 351-364 (1998).

Charnes, A., Cooper, W.W., Rhodes, E.: Measuring the efficiency of decision making unit, Eur. J.Oper.Res., 2, 429-444 (1978).

Dasgupta, J.: Measuring sustainable development: Theory and application, Asian Dev. Rev., 24, 1-10 (2007).

Emrouznejad, A., LatefAnouz, A.: Data envelopment analysis with classification and regression tree – a case of banking efficiency, Expert Syst., 27, 231-246 (2010).

Fare, R., Grosskopf, B., Lindgren, P.,Roos, P.: Productivity change in Swedish pharmacies 1980-1989: a non-parametric Malmquist approach, J. Product.Anal., 3, 85-102(1992).

Friedman, J.H.: Multivariate adaptive regression splines, Anal.Stat., 19, 1-67 (1991).

Gali, J.: Multiple equilibria in a growth model with monopolistic competition, Econ.Theory, 8, 251-266 (1996).

Gnegne, Y.: Adjusted net savings and welfare change, Ecol. Econ., 68, 1127-1139 (2009).

Hamilton, C.: Measuring sustainable economic welfare, in Atkinson, G., Dietz, S. and Neumayer, E. eds, Handbook of Sustainable Development, Edward Elgar Publishing, 307-318 (2007).

Hamilton, K., Hartwick, J.M.: Investing exhaustible resource rents and the path of consumption, can. J. Econ., 38, 615-621 (2005).

Hastie, T., Tibshirani, R.J.: Discriminant analysis by Gaussian mixtures, J. R. Stat. Soc., Series B, 58, 155-176 (1996).

Heckman, J., Carneiro, P.: Human capital policy, NBER Workp., (2003).

Isaksson, A.: World Productivity Database: A Technical Description, RST Staff Workp.10/2007 (2007).

Jeon, B., Sickles, R.C.: The role of environmental factors in growth accounting, J. Appl.Econom., 19, 567-594 (2004).

Kumar, S.: Environmentally sensitive production growth: A global analysis using Malmquist-Luenberger index, Ecol. Econ., 56, 280-293 (2006).

Liao, T.W.: Clustering of time series data – a survey, Pattern Recognit., 38, 1857-1874 (2005).

Lo, S.F., Sheu, H.F., Hu, J.L.: Taking CO2 emissions into a country's productivity change: the Asian growth experience, Int. J. Sustain.Dev. World Ecol., 12, 279-290 (2005).

Lozano, S., Gutiérrez, E.: Non-parametric frontier approach to modelling the relationships among population, GDP, energy consumption and CO2 emissions, Ecol. Econ., 66, 687-699 (2008).

Moisen, G.G., Frescino, T.T :Comparing five modelling techniques for predicting for forest characteristics, Ecol. Model., 157, 209-225 (2002).

Muller, M., Information Retrieval for Music and Motion, Springer (2007).

Pearce, D.W., Atkinson, G.: Capital theory and the measure of sustainable development: an indicator of weak sustainability, Ecol. Econ., 3, 103-108 (1993).

Pezzey, J.C.V.: One-sided sustainability tests with amenities, and changes in technology, trade and population, J. Environ.Econ.Manag., 48, 613-631 (2004).

Ray, S.C., Desli, E.: Productivity growth, technical progress and efficiency changes in industrialised countries: Comment, Am. Econ.Rev., 87, 1033-1039 (1997).

Ray, S.: Data envelopment analysis: Theory and technics for economics an operational research, Cambridge University Press (2004).

Reinhard, S., Knox Lovell, C.A., Thijssen, G.J.: Environmental efficiency with multiple environmentally variables, estimated with SFA and DEA, Eur. J.Oper.Res., 121, 287-303 (2000).

Sakoe, H.:Two-level DP-matching--A dynamic programming-based pattern matching algorithm for connected word recognition, Acoustics, Speech and Signal Processing, IEEE Trans., 27, 588-595 (1979).

Silva Portela, M.C.A., Thanassoulis, E., Simpson, G.: Negative data in DEA: a directional distance approach applied to bank branches, J.Oper.Res. Soc., 55, 1111-1121 (2004).

Simar, L.,Wilson, P.W.: Estimation and inference in two-stage, semi-parametric models of production processes, J.Econom., 136, 31-64 (2007).

Solow, R.M.: Sustainability. An economist's perspective, The Eighteen Seward Johnson Lecture, Marine Policy Center, Woods Hole Oceanographics Institution, Woods Hole, Massachusetts (1991).

Stiglitz J. E., Sen, A., Fitoussi, J.P., Rapport de la Commission sur lamesure des performances économiques et du progrès social, Rapport (2009).

Stoever, J.: On comprehensive wealth, institutional quality and sustainable development – quantifying the effect of institutional quality on sustainability, J. Econ.Behav.Organ., 81, 794-801 (2012).

Stokey, N. L.: Are There Limits to Growth?, Int. Econ.Rev., 39, 1-31 (1998).

Tyteca, D.: Linear programming models for the measurement of environmental performance of firms – concepts and empirical results, J. Product.Anal., 8, 183-197 (1997).

Varvarigos, D.: Environmental degradation, longevity, and the dynamics of economic development, Environ.Resour.Econ., 46, 59-73 (2010).

Xepapadeas, A.: Economic growth and the environment, chap. 23, 1219-1271 in Mäler, K. G. and Vincent, J. R. eds., Handbook of Environmental Economics, 3, Elsevier (2005).

Zhou, p., Ang, B.W.: Decomposition of aggregate CO2 emissions: A production theoretical approach, Energy Econ., 30, 1054-1067 (2008).