Technological Forecasting & Social Change 106 (2016) 108–114

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

The sustainable competitiveness of nations

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ARTICLE INFO

Article history:
Received 15 October 2015
Received in revised form 16 February 2016
Accepted 27 February 2016
Available online 23 March 2016

Keywords:
Global competitiveness index
World Economic Forum
US Council of Competitiveness
Millennium development goals
SDGs
Sustainable development goals
Data envelopment analysis
Frontier analysis

ABSTRACT

Is it possible for a country to be commercially competitive and at the same time protect the environment and social welfare? The recent (2011) initiative by the World Economic Forum to complement their well-known competitiveness rankings of nations with data on sustainability is here reinterpreted in terms of a general model of social and economic policy, using productivity and sustainability variables as policy goals, and the eleven so-called "pillars" of the Forum as policy instruments. Aiming further than just calculating a simple index, however, we consider the full multi-dimensional problem facing each nation maximizing its social preference for the goals, given its corresponding social policy costs. The solution to this optimization problem splits the nations into two categories: (i) those achieving the maximally doable, tracing the "frontier" or upper envelope to the scatter of data points and (ii) sub-optimal and thus under-achieving nations falling behind the envelope. Using the Forum data for 125 nations in 2013, we identify the frontier and sub-frontier nations. For each suboptimal nation we identify its "peers" on the frontier suggesting how its sustainable competitiveness might be improved.

1. Introduction

The US Council on Competitiveness located in Washington, DC, was founded during the Reagan administration in 1986. Its professed goal is to increase the economic competitiveness of the United States in the global marketplace. It sponsors conferences, seminars, and special events, and publishes annual reports of its findings.[1] During its early years, the Council compared and ranked the US performance relative to that of other large countries, but more recently has been mainly occupied with in-depth studies of the US economy.

Throughout, the Council defines competitiveness as "productivity", measured as output per worked man hour. Productivity depends on both the quality and features of the output and the efficiency with which it is produced. Sustained productivity growth requires that an economy continually upgrade its productivity in existing industries by raising product quality, adding desirable features, improving product technology, or boosting production efficiency.

During its early years of operation, the US Council was very much influenced by the ideas of Harvard Professor Michael Porter, the author of *The Competitive Advantage of Nations* (1990).

Porter dismisses many commonly accepted indicators of competitiveness such as labor costs, exchange rates, economies of scale or bountiful natural resources. Instead he finds the true source of competitive advantage on the national level to be productivity.

The World Economic Forum based in Geneva started the calculations of its Global Competitiveness Index in 1979 (see the annual *Global Competitiveness Reports* issued by the Forum). It recognizes twelve "pillars" or causative factors that influence competitiveness such as health and primary education, higher education and training, financial market development, technology and innovation. Each of these categories is broken down into a large number of subgroups. We shall here refer to these pillars as competitiveness "facilitators." A panel of World Economic Forum advisors in each country affixes a competitiveness "value" (on a 1 to 7 scale) to each subgroup, and a constant weight (the weights are the same for all countries, adding to one). The value for each pillar is obtained as the arithmetic weighted average of the values of the subgroups. Finally, using constant weights for each pillar as well, an overall competitiveness index for the entire country is calculated.

Briefly, the World Economic Forum breaks down the concept of competitiveness into its smallest component causal factors, calculating an overall index as an arithmetic weighted average of the values of the factors.

We do not view the two schools of competitiveness studies now outlined, one pursued on each side of the Atlantic Ocean, as competing

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[1] Commemorating its two first decades of operations, the US Council issued the report The Competitiveness Index: Where the US stands (2006). Among recent reports of the council, see in particular the annual 2013 report.

http://dx.doi.org/10.1016/j.techfore.2016.02.017
0040-1625/

approaches. Instead, we view them as complementary. One of these schools puts the emphasis of the various indications or manifestations of competitiveness, that is, the *outputs* of the competitiveness process, the other on the explanatory factors or the *inputs* into the process.[2]

2. Sustainable competitiveness

In economics, the term "sustainable" originally referred to the absence of degradation of natural resources. Lately, it has become common to use the term also in relation to the absence of degradation of social and human conditions generally. The 1987 Brundtland report[3] defined it in the following manner:

> *Sustainable development … meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains … the essential needs of the world´s poor, to which overriding priority should be given… In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.*

In the modern world, the conservation of natural resources is typically obtained through alternative and innovative technology. Fossil fuels are saved through solar or wind power, the fish population of the seas is replenished by fish farms, the release of CO_2 is reduced through the installation of exhaust controls. In brief, sustainability is promoted by innovation and new technology.[4]

In September 2015, world leaders met at the UN in New York adopting a universal agenda setting seventeen SDGs (sustainable development goals).[5] With these agenda the term "sustainability" is taking on a yet wider and more general political significance. While the universality of the new SDGs is commendable, it must be remembered that no sustainability can endure without a steady flow of new technology. Sustainability requires creativity: an ongoing upgrading of existing technology, new lines of production, the startup of new companies and a gradual phasing-out of obsolete technology (through Schumpeterian creative destruction). Often, sustainability requires the daring introduction of entirely new ways of doing things (the invention of better solar cells or new batteries, the discovery of new vaccines to fight deadly disease).

The ninth SDG goal reads:

> "*Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.*"

That formulation is not good enough. For one thing, the era of industrialization is now approaching its end in the Western world. The number of workers in manufacturing is rapidly falling. New jobs based on entirely new technologies need to be created.

To get things right, sustainability needs to be anchored to the idea of increased labor productivity. The World Economic Forum in Geneva is on the right track when it proposes examining the "*sustainable competitiveness*" of nations, defined as "the set of institutions, policies, and factors that determine the level of productivity of a country while ensuring the ability of future generations to meet their own needs".[6] The sustainable competitiveness index (SCI) of the Forum widens the calculation of its standard competitiveness index to include characteristics of demographics, social cohesion and environmental stewardship. The statistics covers nine social sustainability factors and ten environmental sustainability factors.[7]

The great merit of the Forum approach is to break down the competitiveness concept into its underlying technologies, examining each one of these in terms of its social and environmental impact.

Following the Forum, we have for our empirical work chosen four of its social factors (the Gini index, youth unemployment, access to sanitation, access to improved drinking water) and four environmental factors (agricultural water intensity, CO_2 intensity, the overexploitation of fish stocks, forest cover change). The Forum obtains data for these factors from opinion surveys carried out worldwide.

To measure the sustainable competitiveness achievements of a nation — the manifestations or *outputs* of the competitiveness process, we follow the US Council of Competitiveness in turning first to a conventional measure of productivity (GDP per employee) but tempering it by the Forum sustainability records. In effect, this means constructing a joint performance index. For the *inputs* promoting the competitiveness of a nation, we shall simply use the twelve "pillars" used by the Forum in its standard competitiveness index. For both the outputs and the inputs, an index of the component factors has to be constructed. Parting ways with conventional index calculations, however, rather than using fixed and predetermined weights throughout, we shall determine the optimal weight to be given to each factor, thus enabling us to form the ratio between the optimally weighted outputs and the optimally weighted inputs.

Before turning to these particulars, we briefly explain how our approach should be understood as an instance of a general theory of economic and social policy-making in a turbulent world.

3. A measure of the effectiveness of social and economic policy[8]

Social and economic policy deals with the control of policy parameters or instruments of policy that are employed in order to reach some list of policy aims or goals. Quite generally, we shall define the effectiveness of social and economic policy as the ratio between the index of all policy goals achieved and a corresponding index of all policy instruments employed. The competitiveness of a nation will then be measured as the ratio thus obtained.

In order to demonstrate what has now been said, let us assume that a policy-maker has agreed on a list of reasonable policy indicators and collected statistics measuring them, say Y_r, $r = 1, 2,\ldots s$. Also, define a weight to be attached to each such indicator, μ_r, $r = 1, 2,\ldots s$. The resulting goal index would then be $\Sigma_r \mu_r Y_r$. Similarly, assume that the policy-maker has identified a list of competitiveness policy instruments, say X_i, $i = 1, 2,\ldots, m$ with the weights of each instrument ν_i, $i = 1, 2,\ldots, m$ to be determined. The index of policy instruments is then $\Sigma_i \nu_i X_i$.

Consider a situation where data for the vectors X and Y have been collected for $j = 1, 2,\ldots, n$ countries, writing the observations for country j more fully as (Y_{rj}, X_{ij}). We wish to determine the effectiveness ratio (or

[2] For further discussion, see Thore and Tarverdyan (2015, pp. 87–90).

[3] See World Commission on Environment and Development (1987). The Rio + 20 Conference held in June 2012 in Rio de Janeiro was a further important milestone strengthening the institutional framework for policies aiming at sustainable development. See the concluding document UN (2012). More recently, during the celebration of the 70th anniversary of the United Nations, the Sustainable Development Summit 2015 was held from 25 to 27 September 2015, in New York. After the successful conclusion of the negotiations on the post-2015 development agenda at the high-level plenary meeting of the General Assembly an outcome document entitled "Transforming Our World: the 2030 Agenda for Sustainable Development" was agreed by consensus. "A plan of action for people, planet and prosperity" and a set of global "Sustainable Development Goals and targets" was unanimously confirmed by the heads of state of the members of the UN. See UN (2015b).

[4] See F. Phillips, "Toward a Sustainable Technopolis", in Oh and Phillips, eds.,Technopolis (2014, pp. 169–184).

[5] See the 2015a UN *Global Sustainable Development Report.*

[6] World Economic Forum, *The Global Competitiveness Report* (2011–2012, p. 54).

[7] With a media blitz in April 2015, Porter launched his new social progress index (SPI), an impressive attempt to outdo the World Economic Forum, capturing the full dimensions of "social happiness" even extending the calculations to reflect personal freedom and choice. Enlisting the contributions of a worldwide team of economists, the SPI collects statistics on 52 indicators from 133 countries.

[8] The presentation here represents a simplified version of the general theory of economic and social policy presented in Thore and Tarverdyan (2015, pp. 12–18), assuming that the social preference function for all goals can be written as a linear index, and that the social cost function of employing all policy instruments similarly takes the form of a simple linear index.

"effectiveness rating") of each country j. The effectiveness ratio of a particular country $j = 0$ is then:

$$\sum_r \mu_r Y_{r0} / \sum_i \nu_i X_{i0}. \tag{1}$$

The numerical value of the effectiveness ratio will be required to be less than or equal to one:

$$\sum_r \mu_r Y_{r0} / \sum_i \nu_i X_{i0} \le 1. \tag{2}$$

If the ratio equals 1, the policy-maker will be said to be "effective", having identified a list of policy instruments (causes) that provides a full and exhaustive explanation of the goals (that is, the causal effects). But if the ratio falls short of 1, the policy-maker is "ineffective". The possibility of a ratio exceeding 1 is not permitted, as this would indicate that there would exist further explanatory factors (policy instruments) not yet accounted for that remain to be identified in order to provide a full explanation of the goal achievements. The condition (2) can be expressed by stating that the calculated effectiveness ratio be "meaningful". The economic and social policy of a country with an effectiveness ratio equal to one is in equilibrium in the sense of conventional static economic theory. But if the ratio falls below one, the policy is one of disequilibrium or sub-optimality, indicating the presence of policy failure.

The need to look "outside the box" of conventional economic theory in order to understand the failures of national economic policies was at an early point recognized by the International Labor Office (2001).

4. A fractional program

Both the US Council of Competitiveness and the World Economic Forum form their aggregate indices employing fixed and given weights to form their measure of competitiveness, relying on "expert opinion" of individuals or teams of experts. Instead, we shall here determine the weights of the instruments (the ν_i) and the weights of the goals (the μ_r) endogenously by using a process of mathematical programming. More precisely, the program will take the form of a fractional program; it will deliver the optimal weights, the optimal index of instruments, and the optimal index of goals.

The fractional program now to be written down is easy to explain. For any given country, say country $j = 0$, it aims at determining the optimal instrument weights and the optimal goal weights that maximize the effectiveness rating of the country, given that, employing the same weights to form the effectiveness of every single country currently analyzed, the resulting effectiveness rating stays meaningful:

$$\begin{aligned} &\max \Sigma_r \mu_r Y_{r0} \ / \ \Sigma_i \nu_i X_{i0} \\ &\text{subject to} \\ &\Sigma_r \mu_r Y_{rj} / \Sigma_i \nu_i X_{ij} \le 1, \text{all } j \end{aligned} \tag{3}$$

The index weights μ_r and ν_i are considered as unknowns, to be determined by program (3).

Notice that program (3) is undetermined in the sense that if (μ^*, ν^*) solves the program, so does $(k\mu^*, k\nu^*)$ where k is an arbitrary positive constant. To deal with this, one attractive option is to norm the unknown weights so that

$$\Sigma_r \mu_r Y_{r0} = 1, \tag{4}$$

that is, setting the weighted index of all the goals equal to unity. The effectiveness rating of the given country then simply equals one divided by the weighted index of all the policy instruments. Adjoining Eq. (4) to Eq. (3) and rearranging, one obtains the linear program

$$\begin{aligned} &\min \Sigma_i \nu_i X_{i0} \\ &\text{subject to} \\ &-\Sigma_r \mu_r Y_{rj} + \Sigma_i \nu_i X_{ij} \ge 0, \text{all } j \\ &\Sigma_r \mu_r Y_{r0} = 1, \\ &\nu_i \ge 0 \text{ all } i, \ \mu_r \ge 0 \text{ all } r \end{aligned} \tag{5}$$

The observant reader will notice that program (5) actually amounts to a case of "data envelopment analysis" (DEA), originally due to Charnes et al. (1978). The DEA formulation provides access to the calculation of the *envelope* to the given country observations — the piecewise linear upper hull circumscribing them. (A technical definition of the envelope will be provided in Section 6 below.) If the effectiveness rating (3) of a given country turns out to be equal to one, the country observation is located on the envelope itself, but if it is less than one, it is located behind it.

The present study using DEA to rate the economic and social achievements of nations draws on earlier work by Golany and Thore (1997a,b), Thore and Tarverdyan (2008, 2009), Cooper et al. (2010), and, more recently, Thore and Tarverdyan (2015).

5. Calculations

Returning now to our present aim of determining the sustainable effectiveness of nations, we identified the following eight goals $Y1$, $Y2$,…,$Y8$ of competitiveness policy.[9]

Productivity:

Y1: GDP per person employed, in 1990 US dollar equivalents (purchasing power parity).

Factors of social sustainability:

Y2: Equality of the income distribution, calculated as 1 — the Gini index,
Y3: Youth employment (percent of labor force ages 15–24 being employed),
Y4: Access to sanitation (percent of population using improved sanitation facilities),
Y5: Access to improved drinking water (percent of population).

Factors of environmental sustainability:

Y6: Agricultural water conservation (calculated as 1 — withdrawals, as a percent of total renewable water resources),
Y7: CO2 release limitation (kg of CO_2 per kg of oil equivalent energy use, calculated as the maximum of 5 kg minus amount actually released),
Y8: Forest cover conservation (calculated as 100 + average annual percent change of forest area, positive or negative).

As instruments of competitiveness policy we recognize the twelve pillars of the Forum, here to be denoted $X1$, $X2$, $X3$,…,$X12$.

For the numerical solution we used data for 2012 throughout. We gratefully acknowledge access to the sustainability data $Y2$–$Y8$ data and the twelve "pillars" $X1$–$X12$ as assembled by the World Economic Forum. The definitions are those of the Forum. It helps to select variables with acceptable data coverage, yet the variables $Y2$–$Y8$ include many countries with one or more data missing. In

[9] For the sake of easy reading, the subscripts of the Y and X variables are here and in the subsequent elevated to the main line.

Table 1
Goals of competitiveness policy recorded for the ten frontier countries serving as peers ("references") to the largest number of sub-frontier countries.

Country	*Y1*	*Y2*	*Y3*	*Y4*	*Y5*	*Y6*	*Y7*	*Y8*	Number of refs
	GDP, $	1-Gini	Youth empl. %	Access sanitation, %	Access water, %	Water conserv, %	CO_2, %	Forest conserv. %	
Venezuela	36,900	76.3	79.4	100	100	5.0	2.9	98.3	25
Pakistan	8,500	70.0	92.3	48	91	0.7	3.1	98.9	17
Slovak Rep	33,500	74.7	66.0	100	100	4.8	3.0	97	14
Moldova	15,200	67.0	86.9	87	97	3.5	3.6	101	14
Armenia	29,300	68.7	64.6	91	100	1.3	3.3	100	9
US	68,400	61.1	84.5	100	99	2.1	2.5	95.9	9
Slovenia	36,900	76.3	79.4	100	100	5.0	2.9	99	8
Kazakhstan	25,400	71.0	96.1	97	93	1.0	1.7	99.8	8
Algeria	11,300	64.7	75.2	95	84	1.6	1.9	97.6	7
Uruguay	24,500	54.7	81.6	96	99	4.1	3.4	122	7

this fashion 43 countries of the original data set of 125 countries ended up being discarded from the calculations. Our final set thus was made up of 82 countries.

Unfortunately, there exists no generally accepted way in DEA of handling cases of missing observations. Perhaps the most important loss is the exclusion of China with no reported data on its youth unemployment (the variable *Y*3). The possibility to salvage some information from the excluded countries is discussed in the footnote below.[10]

6. The frontier

Solving program (5) for all 82 countries and calculating the effectiveness rating $\Sigma_r \mu_r{}^* Y_{r0}/\Sigma_i \nu_i{}^* X_{i0}$ for each of them (the asterisk indicates the optimal value), it turned out that 54 countries reached the maximal effectiveness rating of 1. As we shall see in a moment, these countries are then all located on the upper envelope to the data points. In our case, the data thus happen to be quite scattered, generating an upper frontier with a large number of linear facets.

To define the upper envelope (or upper conical hull), consider the composite observation

$$(\Sigma_j\ X_j\ \lambda_j\ ,\ \Sigma_j\ Y_j\ \lambda_j) \tag{6}$$

where λ_j is a vector of nonnegative weights (one weight for each observation $j = 1,2,\ldots,n$) summing to unity. Then any observation with the coordinates (X_0, Y_0) lies on the goal frontier or envelope if there exists no composite observation so that

$$\begin{array}{l} \Sigma\, Y_j\, \lambda_j \geq Y_0 \\ X_0 - \Sigma\, X_j\ \lambda_j \quad \geq 0 \\ \lambda \geq 0. \end{array} \tag{7}$$

Such an observation can also be said to be goal-undominated. There exists no other composite observation producing the same goals but using less or the same policy instruments. But if such a composite exists, the observation (X_0, Y_0) is dominated and it lies below the envelope.

[10] As mentioned, data on one or several indicators of social or environmental sustainability were missing in a distressing number of cases. We would therefore like to indicate a possible way of salvaging information from the excluded countries. This suggestion is based on the observation that only goal outputs were sometimes missing, never policy parameter inputs.
Replace all missing outputs by a small positive number. Then running DEA for each country to be amended, rating its performance in relation to that of the entire population of countries, solve for its maximal possible output (that is, the country is projected onto the envelope where the output point indicates the maximal output that the given inputs can sustain). Finally, replace the missing output by the envelope thus calculated, and the DEA is run again. In plain English, this procedure would replace a missing output by the "best" output, but leaves all other outputs unchanged. In most cases it obviously means treating the excluded country a little more favorably than would have been the case, had the true output been known.

Next, consider the dual program to program (5)

$$\begin{array}{l} \max \Phi \\ \text{subject to} \\ \Phi Y_0\ -\ \Sigma_j Y_j \lambda_j\ \leq 0 \\ \Sigma_j X_j \lambda_j\ \leq X_0 \\ \lambda \geq 0 \\ \Phi \text{ unconstrained} \end{array} \tag{8}$$

where Φ is the dual to the normalizing constraint $\mu Y_0 = 1$ and each λ_j, $j = 1,2,\ldots,n$ is the dual to the constraint $-\mu Y_j + \nu X_j \geq 0$. The dual Φ is a number that may be referred to as the "expansion factor." Program (8) seeks the greatest possible factor of equiproportional expansion of the goals $\Phi\, Y_0$ while seeing to it that the expanded point remains goal dominated (there exists no composite frontier observation that uses less policy inputs). This equiproportional scaling up may be thought of as projecting the vector of observed goals onto the envelope.

Note that the effectiveness rating of a country as solved from program (3) equals the inverse of the maximal possible factor of equiproportional expansion of all goals. This follows directly from the duality theorem of linear programming, comparing the direct program (5) with its dual program (8). The projection point onto the envelope lies on a linear facet formed by its corners: the "reference points" or "peers "of the current (non-optimal) observation, serving as role models illustrating the kind of increased goal achievements that would be necessary to reach the frontier.

Using the Banxia Frontier Analyst 3 software, we solved the DEA program for our available 82 countries. Fifty-four of them obtained an effectiveness rating equal to 1, a surprisingly large number, reminding us of the very considerable spread of global competitiveness conditions. However, twenty-one of them served as reference point to no other country; in line with common practice they may then be considered as "outliers". This leaves us with 33 proper frontier countries.

In Table 1 we have brought together the ten frontier countries who serve as peers most often, headed by Venezuela (25 references) followed by Pakistan (17), the Slovak Republic (14), and Moldova (14).

The figures displayed in Table 1 all coincide with the actual observations, as is the case for all frontier points. The list includes countries with very considerable differences between them: The US features by far the highest GDP per person employed but also the considerable inequality of the vertical income distribution (*Y*2) and the weakest record of forest conservation (*Y*8). A poor country like Pakistan has nevertheless a high level of youth employment (*Y*3) and it has a quite commendable CO_2 footprint (*Y*7) and so on. These considerable differences between countries explain why so many of them end up at the frontier: each one of the frontier points possesses a unique mix of outputs that is needed to explain the best practice of one or more sub-frontier countries. The list of frontier countries also includes many countries of the European

Table 2
The ten sub-frontier countries with the lowest effectiveness ratings. For each country two goal figures are shown: first the actual recorded data, second the calculated goal target.

Country	Eff. score	*Y1*	*Y2*	*Y3*	*Y4*	*Y5*	*Y6*	*Y7*	*Y8*
		GDP, $	1-Gini	Youth empl, %	Access sanitation, %	Access water, %	Water conserv, %	CO_2, %	Forest conserv. %
Romania	94.8	11,584/	66.8/	77.3/	72/	88/	4.2/	2.8/	99/
		19,500	70.5	85.2	79.6	92.8	4.4	3.6	104
Germany	94.4	43,200/	71.7/	91.9/	100/	100/	3.1/	2.7/	98.1/
		45,800	76.0	97.4	100*	100*	3.3	2.9	111
Russia	94.2	19,700/	59.9/	85.2/	70/	97/	3.8/	2.5/	99/
		23,900	63.6	98.7	81.9	100*	4	3.0	109
Czech Rep.	94.1	26,800/	75.1/	80.5/	100/	100/	3.9/	2.5/	99/
		32,700	79.8	85.6	100*	100*	4.3	3.2	110
Malaysia	91.6	24.900/	53.8/	90.0/	96/	100/	2.9/	2.0/	92.8/
		27,100	70.9	98.0	100*	100*	3.2	3.2	111
Lithuania	91.3	28,700/	68.0/	73.6/	94/	96/	3.8/	3.1/	97.3/
		31,400	77.4	81.2	100*	100*	4.1	3.3	108
New Zealand	90.5	36,600/	67.7/	82.3/	100/	100/	3.7/	3.3/	100.3/
		40,400	80.5	91.0	100*	100*	4.0	3.4	113
Poland	89.3	27,500/	69.1/	73.5/	89/	98/	3.7/	1.9/	99.5/
		32,500	77.4	88.3	100*	100*	4.1	3.2	112
Philippines	89.1	8700/	57.0/	82.4/	74/	92/	1.7/	3.0/	98.1/
		18,300	72.3	92.5	83.1	100*	2.2	3.4	110
Indonesia	79.8	11,500/	61.9/	78.4/	59/	85/	1.7/	3.0/	94.5/
		18,900	77.5	100*	76.1	100*	2.3	3.7	118

Union, but these are less "popular" as they have only a few followers looking upon them as their peers.

7. Sub-frontier countries

The first and immediate way of characterizing a sub-frontier country is to look at its effectiveness ratio $\Sigma_r \mu_r Y_{r0}/\Sigma_i \nu_i X_{i0}$, as solved from program (5). It ranks the sub-efficient countries from the more successful ones (a ratio close to one) to the less successful ones (low ratios).

(Note that the effectiveness rating is not an "index" in the common sense of conventional index procedures. The envelope points all score the rating of 100%. They are "equally good". But in the sense explained, the effectiveness rating does rank the sub-envelope countries, from those very close to the frontier (rating near 100%) to those at the bottom of the list.

Table 2 lists the results for ten laggards: the ten sub-frontier countries with the lowest effectiveness scores. For each country it shows its effectiveness rating and the eight goals *Y*1, *Y*2,…,*Y8*. Each goal cell displays two goal figures: the actual recorded goal achievement of the country and the projection on the envelope, that is, the maximal possible goal result ("best practice") as defined by its peers.

Several of the goal variables are expressed as percentage points. The forest conservation ratio *Y*8 can be greater than 100 but the others cannot. Solution percentage points greater than 100 have then been indicated by the notation 100* (the explicit introduction of such upper limits in the math program itself should be avoided, as it would disrupt the interpretation of its solution as the envelope). Such values indicate that the inefficient country is scored against a difficult-to-realize target of performance.

Why do the ten counties listed in Table 2 obtain so unfavorable results? To indicate an answer, take a look at the accompanying Table 3 listing the peers of each of those ten laggards. For each country, its peers jointly define the corresponding facet on the envelope frontier. "Best practice" is the projection $\Phi^* Y_0$ of the observed point onto that facet. The possible attendant improvements can be read from Table 2. Note that many peers are located geographically close to and share many of the demographic and cultural characteristics of the country currently examined. This makes eminent sense, of course.

For Indonesia and several of the other countries the weights add up to more than 1, indicating that the projection onto the frontier involves not only forming an arithmetic average of the peer points but also a radial expansion.

Another observation: many peer countries possess advantages that it may be difficult for others to copy. Venezuela, experiencing a dramatic oil boom at the time, is one example. The high ratings of youth employment in agricultural countries like Pakistan may also be difficult for others to match.

Table 3
For each country listed in Table 2: its three most important peers with their λ_j weights.

Country	Peers (with their λj weights)
Romania	Slovak Rep. (0.29), Moldova (0.25), Cameroon (0.21)
Germany	Venezuela (0.31), Austria (0.25), US (0.23)
Russia	Venezuela (0.54), Bolivia (0.46)
Czech Rep.	Slovak Rep. (0.59), Venezuela (0.22), Kazakhstan (0.16)
Malaysia	Venezuela (0.33), Guatemala (0.30), Kazakhstan (0.18)
Lithuania	Slovenia (0.28), Moldova(0.24), Armenia (0.23)
New Zealand	Norway (0.32), Moldova (0.28), Armenia (0.22)
Poland	Slovak Rep. (0.49), Venezuela (0.47), Moldova (0.08)
Philippines	Pakistan (0.36), Moldova (0.29), Venezuela (0.18)
Indonesia	Pakistan (0.56), Venezuela (0.39), Sri Lanka (0.10)

8. The case of Switzerland

In order to demonstrate how the results of the envelopment calculations can be used, we have chosen to look in some depth at the results for one single country: Switzerland. As it so happens Switzerland turns out to be located slightly behind the envelope, scoring an effectiveness rating of $\Phi^* = 96.4\%$. Its sustainable efficiency is suboptimal

Important clues how the performance of Switzerland could be improved is provided by the Peer analysis in Table 4. The "peers" are those countries that lie closest to Switzerland on the envelope, spanning the linear facet onto which Switzerland can be projected. Switzerland has six peers: Moldova, Norway, USA, Sweden, Guatemala and the Slovak Republic. The λ_j weight of each country is indicated in the heading.

As the figures suggest, the achievements of Switzerland are certainly respectable. There is a high degree of equality in its income distribution. The youth employment rate is high. The Swiss achievements of social sustainability (goals *Y*4 and *Y*5) are ideal (100%). But the record on environmental sustainability (goals *Y*6, *Y*7 and *Y*8) is not quite up to par.

Table 4
Switzerland and its peers. The figures in columns (2) through (8) are all observed data for 2012. The last column ("goal target") shows the optimal solution for Switzerland.

Goal	Switzerland	Moldova weight 0.37	Norway weight 0.35	USA weight 0.18	Sweden weight 0.10	Guatemala weight 0.06	Slovak R weight 0.04	Goal target
*Y*1 GDP, $	41,900	15,200	51,400	68,400	52,380	13,200	33,500	43,500
*Y*2 1-Gini	71.3	67.0	77.4	61.1	75.2	44.9	74.7	76.0
*Y*3 Youth empl.	91.6%	86.9%	91.5%	84.5%	76.4%	95.1%	66.0%	95.0%
*Y*4 access sanitation	100%	87%	100%	100%	100%	80%	100%	100* %
*Y*5 access water	100%	97%	100%	99%	100%	94%	100%	100* %
*Y*6 water conserv.	3.9%	3.5%	4.6%	2.1%	3.7%	4.0%	4.8%	4.1%
*Y*7 CO2	3.5 kg	3.6 kg	3.2 kg	2.6 kg	4.0 kg	3.9 kg	3.0 kg	3.7 kg
*Y*8 forest conserv.	99.2%	100.9%	98.2%	95.9%	95.9%	89.4%	97%	107.4%

Notice also that although some of the peers are poor countries with results that in several respects fall short of those of Switzerland, every single peer outshines Switzerland in one way or another. Moldova excels in the two goals *Y*7 and *Y*8. Norway excels in terms of *Y*1, *Y*2 and *Y*6. USA, the richest kid on the block, excels in its GDP per person (but nothing else). Guatemala delivers a strong showing of *Y*3 and *Y*6, the Slovak Republic on *Y*2 and *Y*6.

The last column in Table 4 displays the "target" goal values for Switzerland ("best practice"). Each target can be written as the weighted average of the actual results of the peers (the weights do not necessarily add up to 1).

Note that all goals reached by Switzerland fell short of their targets. In fact, they could all be increased by 1.04% (calculated as 1: 96.4). The Swiss goal data can be "projected" onto the envelope of effectiveness by inflating them equi-proportionally by the factor 1.04. The projection point is located on the linear facet spanned by the corner points of the peers. In this sense, those six peers out of all 33 peers that define the envelopes are the ones "closest" to Switzerland.

To demonstrate how the identification of the peers can be used by policy-makers, let us compare the optimal solution for Switzerland with that of its two most important peers: Moldova and Norway. The figures as percentage points of the corresponding results for Switzerland are:

	Moldova	Norway
goal *Y*1 (GDP in US $)	36.2	122.7
goal *Y*2 (1-Gini)	93.9	108.6
goal *Y*3 (youth employment)	94.9	100.0
goal *Y*4 (access to sanitation)	87	100
goal *Y*5 (access to drinking water)	97	100
goal *Y*6 (agricultural water cons.)	89.8	116.7
goal *Y*7 (CO2 release)	101.7	91.7
goal *Y*8 (forest conservation)	101.7	99.0

Most results for Moldova fall short of the Swiss achievements. For instance, the Moldova GDP per employee would only be 36% of the corresponding Swiss figure. But there are two exceptions: goal *Y*7 (CO_2 release) and goal *Y*8 (forest conservation). For these two, Moldova beats the Swiss figures. So, is Moldova a "peer" to Switzerland or not?

To answer this question, now take a look at Norway, a peer country to Switzerland with almost the same weight as Moldova. Here, the picture is quite different. Norway beats the best goal achievements of Switzerland in terms of productivity (*Y*1), income equality (*Y*2) and agricultural water conservation (*Y*6) and matches the Swiss optimal solution for sanitation (*Y*4) and drinking water (*Y*5).

So, each peer illustrates the possibility of excellent performance in terms of some goal. In the case of Moldova, it is CO_2 release and forest conservation; in the case of Norway it is productivity, income equality and agricultural water conservation. The "target" for Swiss policy as suggested by the optimal programming solution is to find the optimal balance between the policies of its peer nations.

9. Concluding remarks

In the pages above we have shown how it is possible to adapt a general measure of the effectiveness of social and economic policy to rate the achievements of nations in terms of their "sustainable competitiveness". The precise definition of this concept is left to the analyst, selecting a list of suitable outputs or goals of competitiveness policy (like productivity, social factors, and environmental factors) and another list of the inputs or policy parameters (like technology, education and health). In our case, and in order to make comparisons easier, we have used as outputs productivity (as used by the US Council of Competitiveness) and seven social and environmental factors (compiled by the World Economic Forum in Geneva.) On the input side we simply borrowed the twelve competitiveness "pillars" of the Forum

Rather than measuring the competitiveness of nations by a single index, we have advocated the use of frontier methods. The pros and cons of these two approaches can be briefly summarized as follows:

Conventional index calculations. Since economists started calculate the gross domestic product of nations, a long line of suggestions have been forwarded to recognize economic progress in more general terms, like the eradication of poverty and care for the environment. A number of indices are currently being calculated by international organizations and other bodies measuring various aspects of social progress or "social happiness".[11] As the coverage of the index is expanded, however, there is the obvious problem of nailing down the exact meaning of the resulting composite. This difficulty is compounded by the challenge to determine the individual weights of each contributing factor. How do you rate the weight of basic nutrition compared to the weight of unpolluted air? And why should these weights be the same for all nations, for the US as well as poor countries in Africa? Furthermore, an index is just a measure of status quo, of how the nation is currently performing (or failing to perform). The index provides no suggestion how things could be improved, no clue to corrective policy.

Frontier calculations. The frontier identifies the subset of nations that are able to coordinate their resources and available policy tools at hand to reach the maximal return of desired ends. The frontier nations define the doable. The nations form a swarm of data points (one point for each nation) in the multi-dimensional space of all goals and all policy instruments. The frontier is the upper envelope to that swarm of points. (It consists of the data points as corner points and linear facets spanned by those corner points.) In a sense, the frontier points are the ones that the protagonists of neoclassical economic theory would bee comfortable with. They represent optimum.

But the frontier points are not ranked. They all represent "best practice". As we have seen, the frontier includes nations from all continents. Some of them are quite poor. So, "best practice" is a quite democratic concept, a status achievable by many. On the other hand, nations located below the frontier are suboptimal. They fall short of the doable. The task of distinguishing between the frontier points and the sub-frontier

[11] See the survey in Thore and Tarverdyan (2015), Chap. 9. ("Beyond GDP").

ones is an empirical one: equilibrium order is not postulated but is a matter of testing, of examining the data.

To each sub-optimal nation one calculates its "peers" — the small number of frontier nations that are "closest" to the nation currently considered. ("Closest" means that they together form the linear facet onto which the nation can be projected through an equiproportional expansion of all its goals.) Each peer outperforms the nation currently considered in terms of at least one goal, but may otherwise fall dramatically short of its other accomplishments. (As we have seen, Guatemala with a GDP per employee less than a third of that of Switzerland, nevertheless beats the Swiss both in terms of youth employment and its CO_2 release limitation.)

The peer analysis thus provides a powerful *diagnostic*, identifying a few role models showing the way toward improved performance. The envelopment analysis not only formalizes the process of social and economic policy, demonstrating the relationship between policy instruments and goals but it actually provides suggestions for redirection and improvements of that policy. Those possible improvements are calculated numerically, drawing lessons from rich and poor nations alike.

Acknowledgments

The authors would like to express their thanks to the World Economic Forum, Geneva for generously making their global competitiveness database available to the Geneva Consensus Foundation and to Banxia Software Ltd. for developing a demonstrative version of Frontier Analyst 4 containing the data analyzed in the article.

References

Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. Eur. J. Oper. Res. 2, 429–444.
Cooper, W.W., Thore, S., Tarverdyan, R., 2010. A utility function approach for evaluating country performances with DEA — the twin goals of decent work and a fair globalization. In: Hockley, L.R. (Ed.), Global Operations Management. Nova Science Publishers, New York, pp. 49–72.
Golany, B., Thore, S., 1997a. The economic and social performance of nations: efficiency and returns to scale. Socio Econ. Plan. Sci. 31, 191–204.
Golany, B., Thore, S., 1997b. Restricted best practice selection in DEA: an overview with a case study evaluating the socio-economic performance of nations. Ann. Oper. Res. 73, 117–140.
International Labor Office, 2001. Reducing the decent work deficit: a global challenge. Report of the Director-General. ILO, Geneva.
Oh, D.-S., Phillips, F. (Eds.), 2014. Technopolis: Best Practices for Science and Technology Cities. Springer Verlag, London.
Porter, M., 1990. The Competitive Advantage of Nations. Free Press, New York.
Thore, S., Tarverdyan, R., 2008. Using data envelopment analysis to screen the possibility of a fair globalization. Port. J. Manag. Stud. XIII, 129–151.
Thore, S., Tarverdyan, R., 2009. Using data envelopment analysis to quantify ILO objectives and identify policies conducive to decent work in a globalized world. Socio Econ. Plan. Sci. 43, 151–164.
Thore, S., Tarverdyan, R., 2015. Diagnostics for a globalized world. World Scientific, Singapore and Now Publishers, Hanover, Mass. Presented and discussed at the World Trade Organization Public Forum in September -October 2015, for a live recording of the pro-ceedings, see R. Tarverdyan, "WTO Public Forum 2015, 2 October 2015". Youtube.
UN, 2012. The future that we want. Concluding document of the Rio + 20 Conference, New York.
UN, 2015a. Global Sustainable Development Report (Edition, New York).
UN, 2015b. Transforming our world: The 2030 Agenda for Sustainable Development, UN GA Resolution A/RES/70/1 (New York).
US Council on Competitiveness, 2006. The competitiveness index: where the US stands, Washington D.C. (see www.compete.org).
US Council on Competitiveness, 2013. Making Impact. Annual Report 2012–2013, Washington D.C.
World Commission on Environment, 1987. Our Common Future. Oxford University Press, Oxford.
World Economic Forum, 2011. The Global Competitiveness Report 2011–2012, Geneva.
World Economic Forum, 2015. Global Competitiveness Report 2015–2016, Geneva.

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