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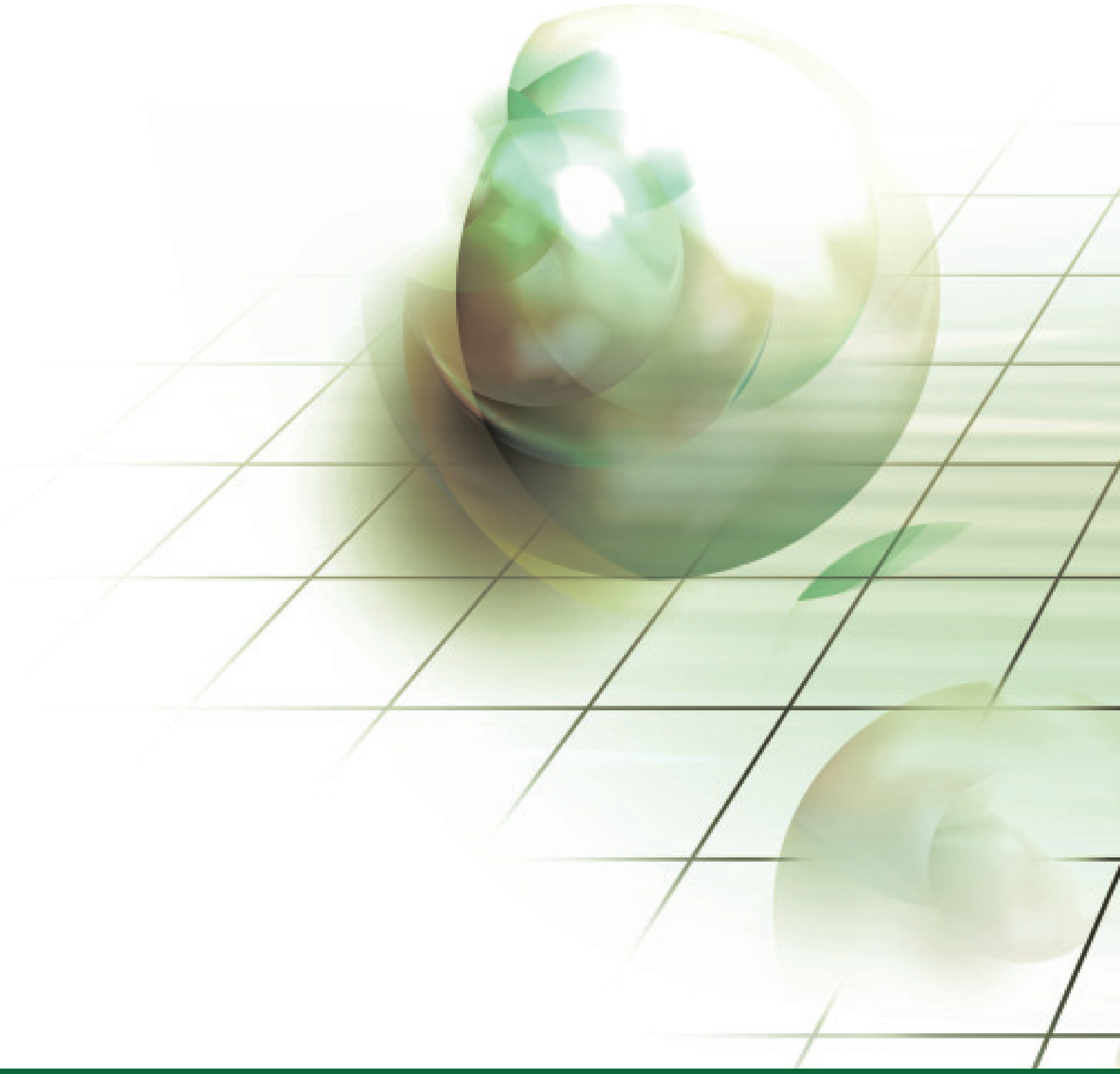
Inclusive Wealth, Total Factor Productivity, and Sustainability



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Inclusive Wealth, Total Factor Productivity, and Sustainability

Masayuki Sato†, Kenta Tanaka‡, and Shunsuke Managi‡

Abstract

Sustainability can be judged by non-declining inclusive wealth, which refers to man-made capital, human capital, natural capital, and all other types of capital that are sources of human well-being. Total factor productivity (TFP) is one important component of sustainability. This study extends current measures of sustainability by capturing the efficient utilisation of natural resources, giving us inclusive wealth-based TFP. Therefore, in contrast to conventional TFP measures, ours considers both human and natural capital in addition to man-made capital. We examine 43 countries and find that in contrast to previous findings, certain countries are not sustainable in contrast to the previous findings.

Keywords: Sustainable development, Inclusive wealth, Total factor productivity

JEL classification codes: Q56, O33, O47

1. Introduction

A promising approach to assessing sustainable development is based on inclusive wealth (IW) (Arrow *et al.,* 2003). Sustainability can be judged by non-declining inclusive wealth, which refers to man-made capital, human capital, natural capital, and all other types of capital that are sources of human well-being. Non-declining inclusive wealth implies the possibility of non-declining human well-being. Therefore, having a theoretically consistent measure of wealth/capital measurement is key in the sustainability evaluation.

The amount of wealth is calculated as the weighted sum of the shadow prices of all types of capital. How the amount of inclusive wealth changes with respect to time, its time differentiation, is often termed genuine savings (GS). GS was first introduced by Pearce and Atkinson (1993), then adopted by Hamilton and Clemens (1999).[1] The concept of GS is considered an extension of savings and investment because it values IW accumulation rather than focusing only on man-made capital investment. This captures factors overlooked by traditional accounting methods. Because GS extends the economic growth model, total factor productivity (TFP) is one important component of GS. TFP includes technological change, efficiency change, and other changes in economic parameters, such as social institutions and individual preferences.

Arrow *et al*., (2004) suggested that TFP plays an important role in using GS to assess sustainability. Two empirical studies incorporated TFP into their GS calculations. In the first, Arrow *et al*. (2004) found the contribution of TFP to inclusive wealth growth rate (i.e. GS per inclusive wealth) to be between -0.40% (Middle East/North Africa) and

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[1] GS is also called genuine investment (Arrow *et al*., 2003), inclusive investment (Dasgupta, 2007), and adjusted net savings (World Bank, 2006). However, these terms all indicate a change in wealth as a source of well-being. This kind of research framework, focusing on capital stock, is called the capital approach. The recent research project by the United Nations Development Corporation (UNDC) developed an inclusive wealth index and stressed the difference between this concept and GS in theoretical assumptions and empirical techniques (see UNU-IHDP and UNEP, 2012). Since we need complete panel data to estimate TFP in our study, we use the data provided by the World Bank. The database is available from http://databank.worldbank.org/.

6.33% (China). In the second, Arrow *et al*. (2012) found the contribution to be between -2.12% (Venezuela) and 2.71% (China). In both studies, the researchers adopted TFP using traditional growth accounting techniques (i.e. capital and labour as inputs, and GDP as an output). However, such a GDP-based TFP ignores the effects of human capital and natural capital, which are key variables in their capital approach.

Because the essence of GS lies in its inclusiveness, the combination of man-made, human, and natural capital is crucial in its calculations. Xepapadeas and Vouvaki (2009) find that the externality of natural capital is considerable in TFP estimations, which drives traditional TFP downwards.[2]

Focusing on the effects of IC, we estimate TFP using GS as an output and each of man-made, human, and natural capital as separate inputs (IW-based TFP). Studies in theoretical literature use the concept of TFP in GS to show a relationship from capital assets (input) to GS (output), and therefore, countries might have different GS values, despite having the same capital assets. In other words, we examine how the level of sustainable development (i.e. non-negative GS) differs among countries with identical input bases. That is, we analyse how these countries differ with respect to the effective utilisation of capital assets. Some countries use their endowed capital efficiently, with appropriate productivity changes and future-oriented stock consumption schemes, while others do not use their capital as efficiently. These differences can affect the respective TFP and TFP-adjusted GS indicators.

In this study, we apply capital asset time-series data to estimate each country's IW-based TFP, which reflects the change in productivity for man-made, human, and natural capital.

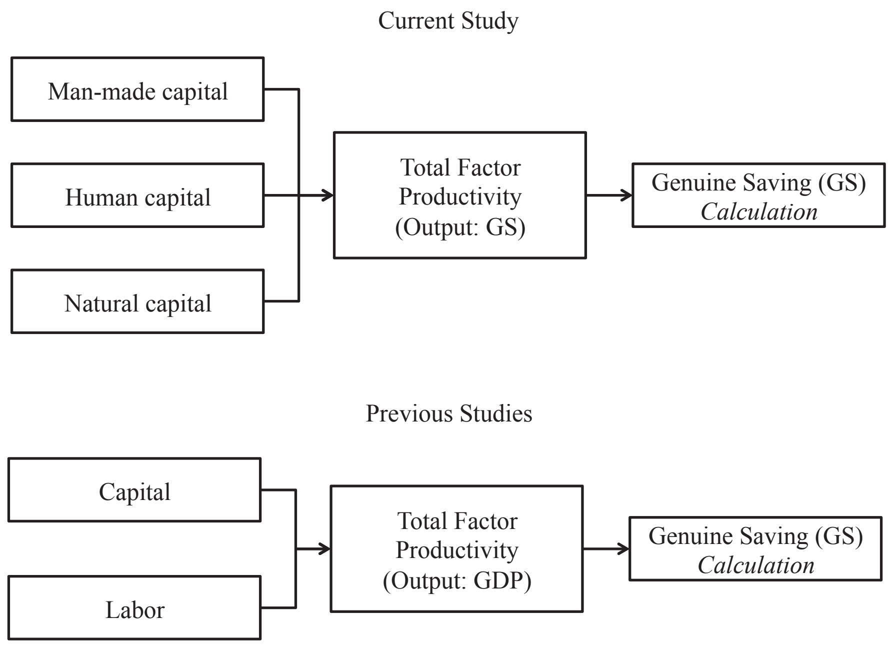

Figure 1. Comparison of the approaches to estimate TFP

The remainder of this paper is organised as follows. Section 2 introduces the basic concepts and previous studies on GS indicators. In Section 3, we discuss the model and the data. Section 4 describes the results, and Section 5 concludes the paper.

[2] Xepapadeas and Vouvaki (2009) apply GDP instead of GS as an output and, therefore, their externality-adjusted TFP is different from that proposed in this study.

2. Previous studies on genuine savings

The Brundtland Commission defines sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development, 1987). In economics terms, many previous studies, such as Arrow *et al*. (2003), define sustainable development as non-declining well-being in the future:

$$V_t = \int_t^{\infty} U(C_t) e^{-\delta(\tau - t)} d\tau \text{ and } \frac{dV}{dt} \geq 0 \text{ for all } t, \tag{1}$$

where V, U, C, and δ represent well-being, current well-being, consumption, and the social discount rate, respectively.

The direct measurement of well-being, V, might be a suitable approach in assessing sustainability, along with equation (1). However, because of the difficulty of observing well-being, Dasgupta (2004) calls for an alternative approach, namely measuring the productive base of V based on the determinants of well-being. This approach focuses on the amounts of all types of capital that contribute to well-being, with the amount of capital representing the productive ability of well-being. This aggregated capital is termed IW, and includes man-made capital, human capital, natural capital, and intangible capital, such as knowledge and institutions. Dasgupta (2004) suggests that non-declining well-being is equal to non-declining IW. Consequently, monitoring the dynamics of changes in IW allows us to assess sustainable development. Accordingly, we can define IW at time t (W_t) as[3]

$$W(t) = P_M M(t) + P_H H(t) + P_N N(t), \tag{2}$$

where $M(t)$, $H(t)$, and $N(t)$ represent man-made capital, human capital, and natural capital at time t, respectively. Each P is shadow price of the capital asset, defined as $\delta V_t / \delta K$, where K is each type of capital. In theory, all types of capital are evaluated using their own accounting prices in the current period.

GS is defined as IW differentiated by time:

$$GS \equiv \frac{dW_t}{dt} = P_M \cdot \frac{dM_t}{dt} + P_H \cdot \frac{dH_t}{dt} + P_N \cdot \frac{dN_t}{dt}. \tag{3}$$

Then, the sustainability condition can be expressed as

$$GS(t) \geq 0 \text{ for all } t. \tag{4}$$

A number of previous empirical studies have been based on the formulations above. For instance, Hamilton and Clemens (1999) calculated the ratios of GS to gross national income for the 1970s and 1980s, and selected single-year values for the 1990s to assess countries' sustainability. Neumayer (2000) estimates GS rates and considers their averages as a yardstick to assess sustainable development. Specifically, the study revises the way the World Bank calculates GS rates by adopting an alternative approach to computing resource depletion. Consequently, the results provide extended and different sustainability results. Similarly, Arrow *et al*. (2004) argue that if a country's average GS rate is negative, it does not meet the sustainability criterion. Further, Hamilton and Atkinson (2006) observe spot GS values, and argue that positive GS values depend strongly on population growth rates. Finally, Arrow *et al*. (2004) explicitly consider TFP when calculating GS.[4] Note that traditional TFP does not consider the

[3] As explained in detail in Section 3, the World Development Indicators (WDI) database includes man-made capital, human capital, and natural capital. However, it includes only man-made capital, education expenditure as a proxy for human capital, and a few types of natural capital depletions, such as energy depletion, mineral depletion, forest depletion, and carbon dioxide damage. Moreover, because data on knowledge capital is unavailable, it is omitted from our formulation.

[4] Arrow *et al.* (2012) also consider the effect of TFP. However, because they adopted another data handling approach, which is not generally available, we use Arrow *et al.* (2004) to focus on the different contributions of GDP- and IW-based TFP.

contribution of natural capital. Arrow *et al*. (2004) merge the TFP data of both Collins and Bosworth (1996) and Klenow and Rodriguez-Clare (1997), which included only man-made capital and human capital, with the elasticities of the two types of capital to output (consumption).

Arrow *et al*. (2004) suggest that neglecting natural capital could cause potential problems in the misspecification of TFP and the elasticity of capital, because it might be possible to overestimate the contribution of TFP in wealth accounting. We compare our results to those of Arrow *et al*. (2004) to examine this possibility. Other than the TFP calculation, we adopt the same definitions and calculation methodology used by Arrow *et al*. (2004), but increase the number of sample countries and years. This comparison provides an interesting insight into TFP calculations for GS-based sustainability assessment.

3. Model and data

3.1 Empirical strategy for estimating IW-based TFP

The basic idea behind TFP is the concept of a time asset. The United Nations University International Human Dimension Programme (UNU-IHDP and UNEP) (2012) treat time as a source of well-being, and extend the model as follows:

$$W(t) = Q(t)t + \sum_i P_i(t)K_i(t), \tag{5}$$

where $Q(t)$ is the shadow price of the time asset; $Q(t)=dV(t)/dt$. The extended identification of IW change is as follows:

$$\frac{dW(t)}{dt} = \sum_i P_i(t)\frac{dK_i(t)}{dt} + Q(t). \tag{6}$$

Our focus on TFP is in the second term on the right-hand side of equation (6), because the temporal change of productivity is an essential component of $Q(t)$.

Equation (6) requires considering IW and each type of capital as an input. Therefore, we apply man-made, human, and natural capital as separate inputs when calculating TFP. Furthermore, the output needs to include wealth change (i.e. GS) in the TFP calculation, based on equation (6). Hence, we map the input of each component (as capital) of IW (instead of capital and labour) to the output of GS data (instead of GDP), and name this IW-based TFP. Because produced goods might be closely connected to the deterioration of natural capital, it is possible for GDP-based TFP to increase over time, and for IW-based TFP to decrease simultaneously. For instance, increasing production (the conventional way to measure GDP) contributes to GDP growth, but may be harmful to the environment. In this case, GDP-based TFP will increase but IW-based TFP may not. Empirically, we check whether these two TFP values are different. As Arrow *et al*. (2004) point out, the adjustment of GDP-based TFP may lead to an overvaluation of the sustainability performance of certain countries.

When TFP, rather than GDP, is used to adjust GS, we also need to consider consumption. For example, assume that two countries both have the same amount of capital stock (inclusive wealth) and same output (GDP). When one country has a relatively low level of consumption, but a high level of investment in a particular year, this country's GS will be higher than the other country's GS in the following year. Because our focus lies in the sustainable use of capital assets, and GS is calculated from capital stock change, we measure the ability of the country to have GS by understanding the linkage between capital assets and GS. In this sense, IW-based TFP specialises in the adjustment of GS,[5] including the change in consumption propensity, and reflects the improvement in capital stock usage toward sustainability. For comparative purposes, we present the results of both IW-based and GDP-based TFP.

Moreover, we adopt the nonparametric frontier analysis of the Malmquist index to measure the TFPs. The index is suitable for assessing the correspondence between inputs and outputs in the case of multivariate inputs. In addition, the measurement takes into account the efficiency of resource use and productivity changes. Using the distance function specification for the index, we can formulate our problem as follows:

$$T(t) \equiv \left\{ \left(x_t, y_t \right) : x_t \text{ can produce } y_t \right\}. \tag{7}$$

Let $x = (x^1, \ldots x^M) \in R_+^M$ and $y = (y^1, \ldots y^N) \in R_+^N$ be the input and output vectors, respectively. The technology set, defined by equation (7), consists of all feasible input vectors, x_t, and output vectors, y_t, at time t, and satisfies certain axioms that are sufficient to define meaningful distance functions. The distance function is defined as

$$d(x_t, y_t) = \min\{\delta; (x_t, y_t / \delta) \in T(t)\}, \tag{8}$$

where δ is the maximal proportional amount to which y_t can be expanded, given technology $T(t)$. This formulation produces an output-oriented distance function. The following data envelopment analysis is used to measure the distance function under constant returns to scale by solving the optimization problem (see Managi, 2003)

$$\begin{aligned} & d(x_t, y_t) = \max_{\delta,\lambda} \delta \\ & s.t. \quad Y_t \lambda \ge \frac{y_i^t}{\delta} \\ & \qquad X_t \lambda \le x_i^t \\ & \qquad \lambda \ge 0, \end{aligned} \tag{9}$$

where δ is the measure of efficiency for country i in year t, λ is an $N \times 1$ vector of weights, and Y_t and X_t are the vectors for outputs y_t and inputs x_t, respectively. To estimate productivity changes over time, several distance functions are used for the input-output vector for period $t + 1$ and the technology in period t. The index (M) is defined by equation (10), using several distance functions:

$$M\left(y_t, x_t, y_{t+1}, x_{t+1}\right) = \left[\frac{d^t\left(y_{t+1}, x_{t+1}\right)}{d^t\left(y_t, x_{tt}\right)} \times \frac{d^{t+1}\left(y_{t+1}, x_{t+1}\right)}{d^{t+1}\left(y_t, x_t\right)} \right]^{1/2}, \tag{10}$$

where d represents the geometric distance to the frontier. This is the best available technology from the given inputs and outputs.

Hence, a country on the frontier can be considered to be the most sustainable under the prevailing resource constraints. Similarly, the distance to the frontier represents the inefficiency of resource use. In other words, a country on the frontier will perform better under the same resource constraints than will a country further away from the frontier.

[5] It may be misleading to use the term IW-based 'TFP', because this concept includes both production and output use. However, because we follow the same procedure for estimation, we use the term TFP.

This index is based on a nonparametric estimation method of data envelopment analysis. Based on this formulation, we estimate the index in the map from capital assets to GS as follows:

$$f:\{P_M M, P_H H, P_N N\} \rightarrow GS. \tag{11}$$

It is possible for two countries to have the same level of capital assets, but different levels of sustainable development, because of how they use their capital assets or saving rates. This difference is captured by the index and reformulated as

$$M\left(GS_t, P_M M_t, L_t, P_N N_t, GS_{t+1}, P_M M_{t+1}, L_{t+1}, P_N N_{t+1}\right) = \left[\frac{d^t\left(GS_{t+1}, P_M M_{t+1}, L_{t+1}, P_N N_{t+1}\right)}{d^t\left(GS_t, P_M M_t, L_t, P_N N_{t+1}\right)} \times \frac{d^{t+1}\left(GS_{t+1}, P_M M_{t+1}, L_{t+1}, P_N N_{t+1}\right)}{d^{t+1}\left(GS_t, P_M M_t, L_t, P_N N_t\right)}\right]^{1/2}. \tag{12}$$

Based on this reformulation, we can analyse the potential increase in GS in each country. As this index is measured by the ratio between two years, a value greater than (less than) one represents an improvement (reduction) in TFP. This index allows us to examine the contribution of TFP to GS by country.

For our comparison, we estimate the GDP-based TFP and observe the differences between the two types of TFP. Equation (12) is based on the reformulated Malmquist index, as follows:

$$M\left(GDP_t, P_M M_t, L_t, GDP_{t+1}, P_M M_{t+1}, L_{t+1}\right) = \left[\frac{d^t\left(GDP_{t+1}, P_M M_{t+1}, L_{t+1}\right)}{d^t\left(GDP_t, P_M M_t, L_t\right)} \times \frac{d^{t+1}\left(GDP_{t+1}, P_M M_{t+1}, L_{t+1}\right)}{d^{t+1}\left(GDP_t, P_M M_t, L_t\right)}\right]^{1/2}. \tag{13}$$

This equation indicates the feasibility of producing goods with fewer inputs. It is thus possible that GDP-based TFP differs from IW-based TFP because the GS in the TFP might increase for all types of capital in inclusive wealth.

3.2 Data

We use the World Development Indicators (WDI) database (http://databank.worldbank.org/) to measure GS. This database contains data on 208 countries and regions from 1970 to 2009. However, as previously noted, GS in the WDI database is defined as the sum of man-made capital investment (e.g. net national savings; dM_t/d_t), human capital investment (e.g. education expenditure; dH_t/d_t), and the damage to or degradation of certain natural resources (e.g. energy depletion, mineral depletion, forest depletion, and CO_2 emissions; dN_t/d_t).

As both flow and stock data are involved, we create datasets for capital stock in each country and each year. In this paper, the stock calculation starts with the results of Kunte *et al*. (1998), which provide a per capita capital stock estimation. In particular, the estimation includes data for subsoil stock and timber and non-timber forest stock. Based on these stock data, we calculate the annual amount of stock using flow data from the WDI (i.e. depletion of energy, minerals, and forests and damage caused by CO_2 emissions).

The data for subsoil stock presented in Kunte *et al*. (1998) correspond to the sum of energy and mineral depletion derived from the WDI. The data for timber and non-timber forest stock correspond to forest depletion (or accumulation) from the WDI database. Based on these data, we calculate the values of each year's capital stock in US dollars in 2000. Our complete dataset panel for this analysis uses data of 43 countries for the period 1970–2005.

4. Results

4.1 Inclusive wealth-based TFP

Using GS data as an output and capital stocks as inputs, we computed the TFP for each country. The estimation results are summarised in Table 1,[6] and the transition and decomposition per decade are summarised in Table 2. The United States shows the highest value. The TFP figures also show that developed countries, such as Japan, France, and the United Kingdom, and developing countries such as Mexico are sustainable. Countries such as China and India show decreasing TFP values over time. On average, the TFP values have been increasing in many countries, as well as per decade. The exception is the 1990s, when efficiency gains contributed more than technological change.

Table 1. Estimated TFP: average for 1971–2004

	Average TFP over 1971 - 2004		Average TFP over 1971 - 2004		Average TFP over 1971 - 2004
Australia	1.0182	Jamaica	1.0033	Thailand	1.0412
Austria	0.9973	Japan	1.0534	Turkey	1.0043
Belgium	1.0101	Kenya	0.9252	United Kingdom	1.0125
Benin	0.9990	Korea, Rep.	0.9857	United States	1.1333
Bolivia	1.0147	Malaysia	1.0112	Venezuela, RB	1.0383
Botswana	1.0149	Mauritania	1.0139		
Canada	1.0226	Mexico	1.4517		
China	0.9981	Morocco	0.9768		
Denmark	0.9917	Netherlands	1.0047		
Dominican Republic	1.0068	Nicaragua	1.0092		
Ecuador	1.0159	Norway	0.9994		
Finland	1.0024	Pakistan	1.0979		
France	1.0071	Philippines	0.9993		
Ghana	1.0060	Portugal	1.0107		
Greece	1.0103	Rwanda	1.0082		
Guatemala	1.0095	Senegal	1.0065		
Honduras	1.0083	Spain	1.0009		
India	0.9724	Sri Lanka	1.0014		
Ireland	0.9917	Sweden	0.9998		

[6] We obtained the TFP results for each year from 1971 to 2004, but only the averages are provided in Table 2 because of space constraints. The overall result is available upon request.

Table 2. TFP summary between the 1970s and 2000s

All countries	TFP in GS	Efficiency Change in GS	Technological Change in GS
1970s	1.0284	1.0275	1.0089
1980s	1.0414	1.0651	0.9872
1990s	0.9975	0.9571	1.0482
2000s	1.0138	1.0443	0.9847

Using the IW-based TFP results, we calculated the growth rates of per capita inclusive wealth. We follow the same process as Arrow *et al*. (2004), with the exception of TFP growth. The results of the calculation are presented in Table 3.[7] Mexico and Japan show higher growth rates of per capita GS (equation (6)) than other countries. The United States is slightly better than China, although both growth rates are increasing.

[7] Note: Collins and Bosworth (1996) use GDP output in their TFP measurement, and Arrow *et al*. (2004) apply these measurements. In Table 4, we adopt the same assumption as Arrow *et al.* (2004). We adjust the TFP scores using a multiplication factor of 1.72 for the TFP growth rate.

Table 3. Estimation Results: Growth rates of per capita inclusive wealth based on IW-based and GDP-based TFPs[8]

	Country	GS per GNI (1)	Growth rate of unadjusted genuine wealth (2)	Population Growth Rate (3)	Growth rate of Per capita Genuine wealth (4)	IW-based TFP Growth rate (5)	Inclusive wealth growth adjusted by IW-based TFP (6)	GDP-based TFP Growth rate (7)	Inclusive wealth growth adjusted by GDP-based TFP (8)
1	Australia	7.2549	1.7292	1.3434	0.3858	2.7413	3.1271	0.0203	0.4060
2	Austria	13.6654	1.9678	0.2785	1.6892	0.3395	2.0287	0.1746	1.8638
3	Belgium	13.8743	2.6183	0.2261	2.3922	1.7085	4.1007	0.2589	2.6511
4	Benin	0.4443	0.0115	3.1947	-3.1832	0.0443	-3.1389	0.1846	-2.9986
5	Bolivia	-2.0251	0.5407	2.2559	-1.7153	0.7102	-1.0051	0.2183	-1.4970
6	Botswana	28.1134	1.2954	2.5422	-1.2469	-0.1059	-1.3527	0.1491	-1.0977
7	Canada	9.7347	2.4631	1.1911	1.2720	4.2694	5.5415	0.1007	1.3727
8	China	15.7264	1.2460	1.3200	-0.0740	9.1296	9.0556	-0.0905	-0.1645
9	Denmark	11.3874	1.5924	0.2569	1.3355	0.3785	1.7140	0.1226	1.4581
10	Dominican Republic	13.1614	0.9328	2.0085	-1.0756	0.4054	-0.6702	0.0185	-1.0571
11	Ecuador	-7.1698	1.1150	2.3060	-1.1910	0.1278	-1.0632	0.2135	-0.9774
12	Finland	12.9313	1.1568	0.3781	0.7787	0.6385	1.4172	0.3037	1.0824
13	France	13.6412	2.2584	0.5052	1.7532	1.1935	2.9467	0.1643	1.9175
14	Ghana	2.0095	0.0298	2.6281	-2.5983	0.2045	-2.3938	-0.3157	-2.9140
15	Greece	14.2537	1.7052	0.6854	1.0198	0.9632	1.9830	0.4449	1.4647
16	Guatemala	2.4897	0.2751	2.4294	-2.1544	0.0056	-2.1488	0.2021	-1.9522
17	Honduras	14.0405	0.2110	2.9879	-2.7769	-0.0773	-2.8542	0.1709	-2.6060
18	India	10.2321	0.5854	2.0083	-1.4229	1.0627	-0.3602	-0.3871	-1.8100
19	Ireland	14.7483	2.6853	0.9521	1.7332	0.2752	2.0084	0.1606	1.8938
20	Jamaica	9.1327	0.1972	1.0120	-0.8147	0.1644	-0.6503	0.9465	0.1318
21	Japan	19.1053	23.6921	0.5771	23.1150	2.1735	25.2884	0.7033	23.8182
22	Kenya	12.5420	0.1216	3.2436	-3.1220	3.1936	0.0717	0.4161	-2.7059
23	Korea, Rep.	22.2910	2.8993	1.1859	1.7134	1.2038	2.9173	0.2017	1.9151
24	Malaysia	13.4488	1.6793	2.4701	-0.7908	0.9132	0.1224	0.3210	-0.4698
25	Mauritania	-17.3458	0.7089	2.5638	-1.8548	0.1184	-1.7364	0.0611	-1.7937
26	Mexico	4.8379	0.6814	2.0521	-1.3707	165.7486	164.3780	0.3336	-1.0371
27	Morocco	14.5214	1.0958	2.0334	-0.9375	-0.1483	-1.0858	0.4411	-0.4964
28	Netherlands	16.1763	3.3185	0.6391	2.6794	0.3015	2.9809	0.0437	2.7231
29	Nicaragua	-7.9548	-0.0059	2.4566	-2.4625	0.0321	-2.4304	0.4469	-2.0156
30	Norway	14.0762	3.0169	0.4939	2.5230	0.6574	3.1804	0.1768	2.6999
31	Pakistan	9.1019	0.4778	2.7293	-2.2516	1.8454	-0.4062	6.4999	4.2483
32	Philippines	15.0021	0.8702	2.3767	-1.5065	0.4109	-1.0956	0.0121	-1.4944
33	Portugal	9.2816	0.6521	0.5952	0.0569	0.8032	0.8601	0.5224	0.5793
34	Rwanda	5.6369	0.3948	2.6083	-2.2135	-0.0815	-2.2950	3.2663	1.0528

[8] The average for all sample countries is 5.61. This implies that the countries on average tend to be judged as sustainable, but there is considerable variation among countries. We should thus pay attention to the interdependency among them and be careful about drawing general conclusions about global sustainability.

35 Senegal	-0.4151	-0.0680	2.7137	-2.7817	0.1813	-2.6005	0.3170	-2.4647
36 Spain	12.2155	1.7027	0.6762	1.0265	0.9035	1.9300	0.2826	1.3091
37 Sri Lanka	14.8434	0.4356	1.3563	-0.9208	-0.0157	-0.9364	-0.2191	-1.1399
38 Sweden	16.1993	2.4656	0.3180	2.1475	0.4843	2.6319	0.0502	2.1978
39 Thailand	19.7857	1.0142	1.6390	-0.6248	7.1610	6.5362	0.1741	-0.4508
40 Turkey	15.2429	0.0202	2.0663	-2.0461	1.1121	-0.9340	0.3114	-1.7347
41 United Kingdom	8.3496	1.9964	0.2053	1.7911	2.1913	3.9824	0.1727	1.9637
42 United States	8.7533	2.3784	1.0556	1.3227	8.3258	9.6485	0.1105	1.4333
43 Venezuela, RB	-3.1724	0.1491	2.6329	-2.4838	14.4187	11.9349	-0.1228	-2.6066

Note: the TFP growth rate (column 5) is calculated as IW-based TFP growth × 1.72 for comparison with Arrow *et al*. (2004).

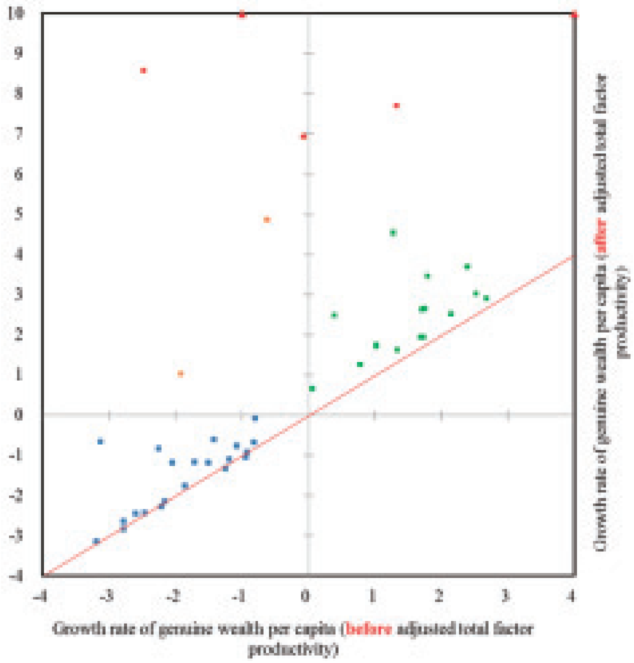

Figure 2. The growth rates of genuine wealth per capita: before and after the adjustment of IW-based TFP

The countries above the 45-degree line in Figure 2 experience a gain in productivity. The figures reflect the scores before revising the TFP values, so may overestimate the scores. In other words, even though the TFP scores are considered to be improving, they may not be. In contrast to Arrow *et al*. (2004), we demonstrate that many countries have positive TFP growth rates, even though their respective of natural capital values have been taken into account.

4.2 Comparison of GDP-based TFP and IW-based TFP results

Using the same methodology, we calculated the GDP-based TFP for each country. This is a productivity measure based on how many economic goods and services are produced given the same inputs. The IW- and GDP-based TFP values are different, as shown in Figure 3 and Table 3. This reflects the fact that GDP based-TFP does not include productivity changes in the utilisation of natural capital or frugality in consumption. In general, a positive relationship is evident (see Figure 3). When the value of one index is positive (negative), the other tends to be positive (negative) as well. Table 3 suggests that the contributions to sustainability are altered by the choice of TFP. Several countries, such as Australia, Belgium, Canada, China, Japan, Mexico, Thailand, the United Kingdom, and the United States have significantly larger IW-based TFP values than conventional GDP-based TFP values. On the other hand, Pakistan and Rwanda have much smaller IW-based TFP values. There are also countries in which the TFP growth values change sign, including Botswana, Ghana, Honduras, India, Morocco, Rwanda, and Venezuela. As the concept of GS includes man-made capital, human capital, and natural capital, in addition to the consumption rate, it is better to use the IW-based TFP figures when assessing sustainability using the GS indicator. These differences contribute to the discrepancies between the two measurements.

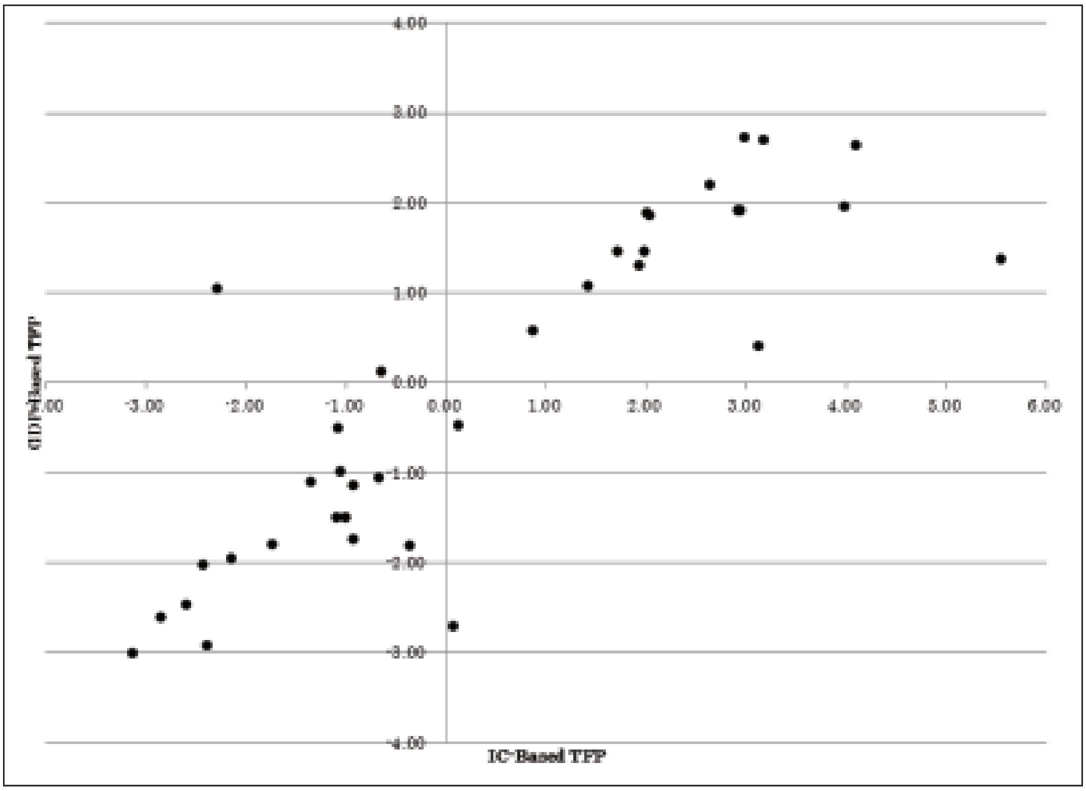

Figure 3. Scatter plot of countries by GDP- and IW-based TFP adjustment

Consequently, IW growth rates adjusted by TFP, which use the TFP value and relate to the value of equation 6, are altered. For example, China has a negative growth in IW, but this becomes a much larger value in terms of IW growth. IW growth in Jamaica, Pakistan, and Rwanda (Malaysia, Mexico, Thailand, and Venezuela) changed from positive (negative) to negative (positive), reflecting a decrease (increase) in TFP, which offset the negative (positive) capital contribution.

We compare our results to those of Arrow *et al*. (2004) because the two datasets have five countries in common (see Table 4). Arrow *et al*. (2004) suggest that the wealth growth of India and Pakistan (when ignoring TFP) is not sustainable. However, both countries are on a sustainable development path when considering TFP growth.[9] On the other hand, even when considering the TFP growth rate, India and Pakistan are not on a sustainable development path, according to our study. Our results suggest that the previous adjustment, using GDP-based TFP, leads to an overestimation of the growth rate of per capita wealth.

[9] This implies that per capita inclusive wealth is increasing over time. In the following discussion, 'sustainable' means an increase in per capita inclusive wealth.

Table 4. Comparison results

	This study		Arrow *et al.* (2004)	
	Before TFP adjustment	After TFP adjustment	Before TFP adjustment	After TFP adjustment
India	-1.42	-0.36	-0.57	0.54
Pakistan	-2.25	-0.41	-1.35	0.59
China	-0.07	9.06	2.06	8.33
United Kingdom	1.79	3.98	1.30	2.29
United States	1.32	9.65	0.72	0.75

Note: The values of this study are derived from Table 3.

Before the TFP adjustment, the path of wealth growth in China is not sustainable. However, when the TFP growth rate is considered, we find the opposite result. Both studies suggest the UK and US are on sustainable development paths. In summary, adjusting IW using IW-based TFP is a better indicator of sustainability.

4.3 Effect of consumption

The inclusive wealth change depends on the amount of investment. If natural capital is depressed, a significant investment is required to compensate for the depreciation and to cause inclusive wealth to increase. Hence, sustainability depends on the level of investment, in other words, in the level of consumption.

The equation representing IW-based TFP also includes the change in consumption propensity. Our estimation of IW-based TFP partially reflects this change. Using the following regression, we add the consumption variable to the explanatory variables used by Dietz *et al*. (2007):

$$\begin{aligned} TFP_t = const + \Delta TFP_{t-1} + \Delta TFP_{t-2} + \Delta C_t + inst_t + RS\_OECD + RS\_NonOECD \\ + Export\_OECD + Exprt\_NonOECD + RS * inst_t + \Delta AGE_t + \varepsilon. \end{aligned} \quad (14)$$

where ΔTFP represents the IW-based TFP growth, ΔC is the consumption growth, *RS* represents a resource-rich country, *OECD* is a member of OECD, *Export* represents a resource exporting country, and *inst* represents the quality of the institution, as measured by corruption, bureaucratic quality, and law and order.[10]

We obtain two estimation results, using the generalised method of moments (GMM) estimate (Table 5) and panel data estimate (Table 6). In the panel data specification, the Hausman test result is not significant, implying a random effect specification.

[10] We use data of the *International Country Risk Guide* (http://www.prsgroup.com/icrg.aspx) for the institution variables.

Table 5. Effect of consumption by system GMM

	Corruption	Bureaucratic quality	Low
ΔTFP_{t-1}	-0.358**	-0.581**	-0.128
	(-1.80)	(-2.05)	(-0.87)
ΔTFP_{t-2}	0.352**		0.177***
	(2.44)	(0.06)	(4.70)
Δ C	-0.863	-0.036	-2.082
	(-1.28)	(-0.06)	(-1.46)
inst	-0.149**	-0.446	0.104
	(-2.29)	(-1.37)	(1.20)
RS_OECD	19.183	-5.019	-9.509
	(1.16)	(-0.22)	(-0.80)
RS_NonOECE	19.931*	-1.472	-0.385
	(1.81)	(-0.11)	(0.07)
Export_OECD	-2.683**	0.877	-1.995
	(-2.20)	(0.97)	(-1.48)
Export_NonOECD	-3.405***	-0.786	-0.970
	(-2.74)	(-1.11)	(-1.40)
*RS*inst*	-4.041	1.152	1.765
	(-1.09)	(0.19)	(0.87)
ΔAGE	-2.382	1.601	-2.065**
	(-1.40)	(0.58)	(-2.16)
c	-0.361	2.148	-1.008*
	(-0.42)	(0.98)	(-1.86)
AR1	-0.95	-1.23	-1.17
AR2	-0.40	-1.04	-0.90

Values in parentheses are t-values. *Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level.

Table 6. Effect of consumption by panel (Random effect)

	Corruption	Bureaucratic quality	Low
ΔTFP_{t-1}	-0.316***	-0.316***	-0.316***
	(-8.25)	(-8.26)	(-8.26)
ΔTFP_{t-2}	0.113***	0.116***	0.113***
	(6.42)	(6.55)	(6.42)
Δ *C*	0.043	0.049	0.052
	(0.43)	(0.48)	(0.51)
inst	0.008	0.013**	0.007*
	(1.55)	(2.11)	(1.67)
RS_OECD	0.373	-0.504	-1.190
	(0.26)	(-0.60)	(-1.03)
RS_NonOECE	0.043	-0.441	-0.673
	(0.06)	(-0.88)	(-1.27)
Export_OECD	-0.247***	-0.250***	-0.241***
	(-2.72)	(-2.80)	(-2.68)
Export_NonOECD	0.011	0.010	0.005
	(0.20)	(0.19)	(0.08)
*RS*inst*	-0.079	0.120	0.186
	(-0.32)	(0.54)	(0.97)
ΔAGE	-0.008	-0.014	-0.018
	(-0.18)	(-0.33)	(-0.40)
c	0.049	0.036	0.043
	(1.47)	(1.10)	(1.31)
R2	0.205	0.209	0.207
Hausman	7.84	5.71	8.47

Values in parentheses are t-values. *Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level.

Both estimates suggest that consumption does not have a significant effect on TFP growth. This implies that our estimation of IW-based TFP is a reflection of capital stock utilisation and productivity change. However, a change in consumption propensity, such as sustainable consumption behaviour, might potentially improve inclusive wealth requires, but whether the consumption level is sustainable requires further research.

We find that institutional quality has a possible effect on the efficient use of resources, as described by Dietz *et al*. (2007). 'Corruption' has a negative relationship with TFP growth in the GMM estimate. 'Bureaucratic quality' and 'Law and order' have a positive relationship with TFP growth in the panel data estimate. In addition, we find there is a relationship between trade and the TFP growth. International trade affects the flow of resources between each country. If some countries focus on exporting resources for economic development, their resources may decrease significantly. The variables capturing trade activities show a negative relationship with TFP growth. In the specification including 'Corruption' in Table 5, 'Export_NonOECD' shows a negative relationship with TFP growth. In addition, 'Export_OECD' shows a negative relationship with IW-based TFP growth.

5. Conclusions

This study extended the sustainability measure of Arrow *et al*. (2004, 2012) by capturing the efficient use of natural resources, namely IW-based total factor productivity (TFP). Our TFP is different to conventional GDP-based TFP in that it considers both human and natural capital, as well as man-made capital. Compared to previous studies, our results suggest that the respective sustainability values are inflated. For example, certain countries, such as India and Pakistan, are not sustainable, which contrasts with previous findings.

We further empirically extended the measures to 43 countries, each of which showed significantly different TFP values, reflecting their varied levels of efficiency in terms of use of resources. This suggested that TFP is useful in assessing sustainable development from the perspective of wealth accounting, including the use of GS indicators. Institution and trade were also found to influence the level of sustainability in our extended welfare measure. Future studies need to extend the data by including more countries and more factors, such as ecological stock in natural capital and human health capital.

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