Inclusive Wealth Report 2018

Methodological Annex: Conventional Approach

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1. Introduction

Within economic policy, there has been an ongoing quest to determine how we can move beyond gross domestic product (GDP) to attain a true indicator of social well-being. The eminent report by Stiglitz et al. (2009) suggested that GDP faces three main challenges: conventional issues, quality of life aspects, and sustainability issues. Despite the arguments that GDP is problematic on many fronts, it does have its uses. It measures the value added in an economy within a certain period and thus acts as a proxy for the extent of economic activity. Here, it is important to remember that Simon Kuznets, one of the fathers of GDP, originally intended to design an index that represents welfare rather than the value added in an economy (Coyle 2015).

Within the vast literature of green national accounting regarding the long-term well-being of an economy, net domestic product (NDP), which is an adjusted index of GDP, has been shown to represent human well-being fairly well (Weitzman 1976; Asheim and Weitzman 2001). NDP is computed from GDP by accounting for changes in capital assets, such as capital depreciation and natural capital depletion. It is in this sense that NDP can, in some ways, represent human well-being but it does not sufficiently represent intergenerational well-being or the sustainability of an economy. Particularly, NDP still includes that portion that is supposed to be allocated to current consumption. Excluding the value of current consumption from NDP leaves us with investment into produced, human, and natural capital− that is, an inclusive wealth index (IWI) (Dasgupta et al., 2015).

What makes our index and the World Bank's genuine savings indicator distinct from GDP is clear[1]. It is calculated from stocks, rather than flows; it measures determinants, rather than constituents, of well-being (Dasgupta 2001). For the latter, it tends to be a matter of subjective well-being, i.e., happiness, life satisfaction (Helliwell et al. 2017, Easterlin 2003, Kahneman et al. 2006, Layard 2005) and other objective outcomes of well-being, such as the Better Life Index (OECD 2014). The Human Development Index (United Nations Development Programme 1990-2016) is a composite index of education and health, in addition to GDP, which is a commendable innovation that has shifted the focus of well-being towards aspects of human capital. Although the HDI was not designed with a focus on sustainability, doesn't theoretically associate the index with social well-being, and doesn't incorporate natural capital, it is nonetheless a crucial component of the long sustainability of nations (Managi, 2015a; 2015b).

[1] See UNU-IHDP and UNEP (2012) for what makes the inclusive wealth index distinct from the World Bank's genuine savings. To be more precise, genuine savings are constructed from flow variables, complemented by stock calculations.

Another strand of the literature advocating to replace GDP with a better, multi-faceted indicator of well-being is flourishing. Fleurbaey and Gaulier (2009) ranked OECD countries by measuring international flows of income, labor, risk of unemployment, healthy life expectancy, household demography and inequalities, along with income. In a similar vein, Jones and Klenow (2016) constructed a welfare index, including consumption, leisure, mortality, and inequality fronts, and they found that these data are highly correlated with GDP per capita, but also deviate. The aspects mentioned above are by all means important; however, our focus places emphasis on the long-term sustainability of determinants of human well-being, thereby leading to the construction of a capital-based indicator.

Of course, no single index can measure every aspect of human well-being, and IWI is not an exception in this regard. Note, in particular, that our IWI says little about the extent to which *current* well-being is achieved in practice, partly because the score of current capital stocks is not fully consumed by contemporaries and also because IWI is by construction a determinant − or *opportunity* − based indicator. It is not meant to be something that can explain the outcomes and constituents of well-being.

In principle, IWI should include a sufficiently broad, ideally exhaustive but not redundant, score of capital assets that is relevant to current and future human well-being. While classical economics focused on the input trio of (produced) capital, labor and land, neoclassical economics has treated capital and labor in the production function. Subsequently, the economics of exhaustible resources included capital and non-renewable resources (Dasgupta and Heal 1974; Solow 1974). In mainstream economics, human capital – the capitalised concept of labor – has also played an important role in how economic growth can be deconstructed (Mankiw et al. 1992). The inclusion of natural capital – going beyond the notion of natural resource stock only – is imperative regarding the sustainability of human well-being. Thus, we have come full circle to attain the ultimate set of capital stocks as productive bases: produced, human, and natural capital.

2. Overall framework

In this section, we outline our underlying framework, which is premised on the body of work in the literature on green accounting, especially under imperfect economies (Arrow et al. 2012). We note that the economy's objective is sustainable development, in the sense that intertemporal well-being at t:

$$V(t) = \int_t^\infty U(C_\tau) e^{-\delta(\tau - t)} d\tau,$$

is not declining. This expression is merely a discounted sum of instantaneous welfare that is depicted in Figure 1. A central assumption is that this intertemporal well-being is a function of capital assets in the economy. Thus, denoting produced, human, and natural capital as K, H, and N respectively, we have the following equivalence between inclusive wealth and well-being:

$$W(K,H,N,t) = V(t) = \int_t^{\infty} U(C_\tau)e^{-\delta(\tau-t)}d\tau,$$

where W is inclusive wealth. Then, sustainable development is equivalent to non-declining inclusive wealth. Formally, we would like to ensure the sign of the temporal change of inclusive wealth:

$$\frac{dW(K,H,N,t)}{dt} = p_K\frac{dK}{dt} + p_H\frac{dH}{dt} + p_N\frac{dN}{dt} + \frac{\partial V}{\partial t},$$

where p_K, p_H and p_K are the marginal shadow prices of produced, human, and natural capital, respectively. Note that aside from the three-capital channel, we have a direct channel through which only the passing of time directly affects well-being. The shadow prices are essentially marginal contributions to the intertemporal well-being of an additional unit of capital in question. They are formally defined by:

$$p_K \equiv \frac{\partial V}{\partial K}, p_H \equiv \frac{\partial V}{\partial H}, p_N \equiv \frac{\partial V}{\partial N},$$

given a forecast of how produced, human, and natural capitals, as well as other flow variables, evolve in the future in the economy in question. In practice, shadow prices act as a weight factor attached to each capital, resulting in the measure of wealth, or IWI:

$$IWI = p_K K + p_H H + p_N N.$$

In practice, we can use W and IWI interchangeably[2]. For sustainability analysis, what we need is the change in capital assets or what we can call *inclusive investment*,

[2] In theory, W is different from IWI, which is calculated based on constant shadow prices. When reckoning the real W, it is obvious that, for example, the last drop of oil should have a different marginal value than the regular drop when it is not scarce. We compute IWI on the premise that the studied period is relatively short.

$$\frac{dW(K,H,N,t)}{dt} = p_K \frac{dK}{dt} + p_H \frac{dH}{dt} + p_N \frac{dN}{dt} + \frac{\partial V}{\partial t}.$$

In our accounting, barring oil capital gains which we elaborate later, we omit the change in the shadow prices for both theoretical and practical reasons. Shadow prices are defined as the marginal changes when there is a hypothetical, small perturbation in capital assets. Thus, for tracking relatively short-term sustainability, it suffices to use fixed, average shadow prices within the studied period. It is also practical to do this for the purpose of our report since fixing shadow prices will enable us to focus on the quantity of change in inclusive wealth.

In addition, if there are large perturbations, such as large project implementation, natural disasters, or financial crises, we must account for the change in shadow prices even within a short time period. We might consider the price change – capital gains on any capital asset – significant because we will accumulate our editions of IWR over the course of the years ahead.

One exception of this rule of constant shadow prices assumed over the studied period is oil capital gains. Oil prices, and commodity prices more generally, are notorious for experiencing fluctuations within relatively short periods of time. Even if the physical quantity of an oil-rich nation does not change, a spike in the oil price will translate into better opportunities for the country because the country can cash in its oil wealth on the market for increased consumption and investment into inclusive wealth. This is particularly relevant for oil-rich nations in the Middle East, where economic powerhouses other than oil-related industries have long been sought. Conversely, net oil-importing countries tend to witness their social well-being being degraded by rising oil prices. We account for this loss of opportunity by allocating global oil capital gains to oil-importing countries according to the current share of oil imports.

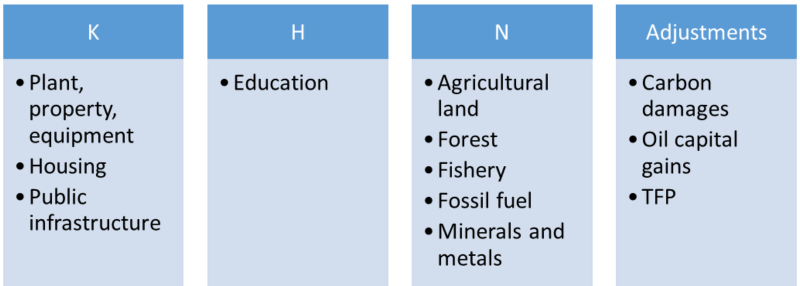
Formally, if we allow the shadow price of natural capital p_N to change, we have,

$$\frac{\partial V}{\partial t} = p_N N \frac{dp_N/dt}{p_N},$$

which represents our capital gain adjustment.

Aside from oil capital gains, there is another important category of adjustment, attributed to our enabling assets. How capital assets are employed and utilised to yield ultimate social well-being can change over time, due to changes in productivity of activities, technological progress, or improvement in social capital. In practice, however, all of these factors should be captured by the change in TFP. Insofar as social well-being improves (deteriorates) more than the individual contributions of capital assets increase (decrease), this residual should also be considered. Arrow et al. (2012) showed that to do this in accounting, we need only to add TFP growth rate to the inclusive wealth growth rate.

Finally, increasing carbon emissions are likely to drive climate change, resulting in devastating socio-economic damages. This aspect of the natural environment will need to be forefront in coming centuries. Current global economic activity is reducing the carbon sink stock of our planet, which can be accounted for as another capital asset in inclusive wealth. We can also tap into the ongoing research on the social cost of carbon in valuing the damages to social well-being accruing from additional carbon emissions. In this report, we continue to adopt the latter approach. In particular, the total global emissions of carbon are evaluated using the social cost of carbon, which is then allocated to individual countries according to the share of the global damage done, which is further subtracted from the inclusive wealth of nations[3]. Figure 1 describes the capital assets which are considered in inclusive wealth.



$$\frac{dV}{dt} = \frac{\partial V}{\partial K}\frac{dK}{dt} + \frac{\partial V}{\partial H}\frac{dH}{dt} + \frac{\partial V}{\partial N}\frac{dN}{dt} + \frac{\partial V}{\partial t}$$

Figure 1: Capital assets under the consideration of Inclusive Wealth

Figure 2 provides our schematic representation of how our three-pillar capital assets, as well as adjustment factors, shape our final index of inclusive wealth. Along with the familiar capital assets that we consider from previous reports (IWR 2012 & 2014), this report adds fishery resource stock to the list of natural capital. In the ensuing sections, we report many aspects of the aggregated figures of inclusive wealth index, both before and after adjustments.

[3] More specifically, the ratio of carbon damage to inclusive wealth can be deducted from the inclusive wealth growth rate to arrive at the adjusted inclusive wealth growth rate.

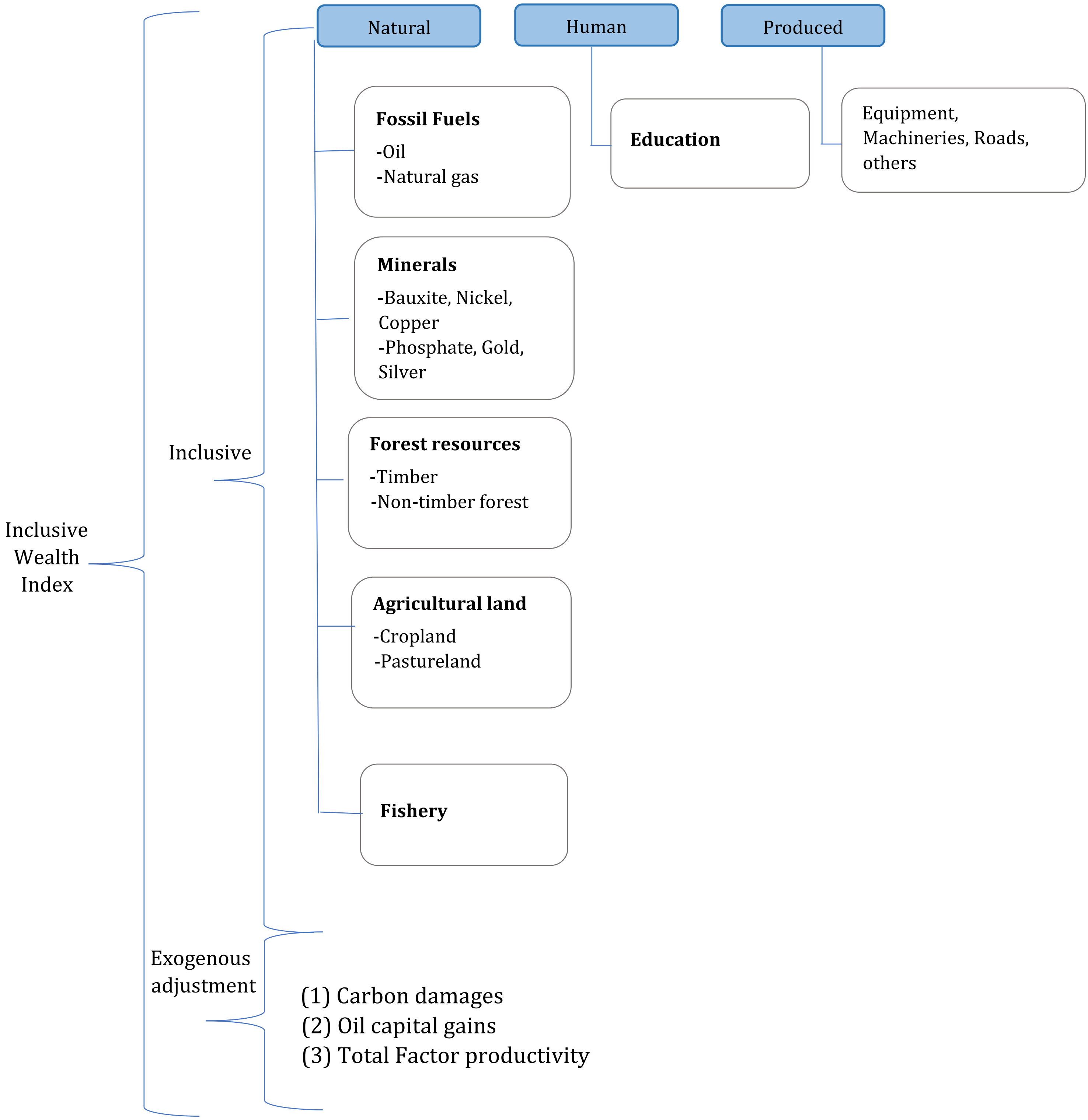


Figure 2: Schematic representation of the Inclusive Wealth Index and the Adjusted Inclusive Wealth Index

3. Produced capital

Produced capital, also referred to as manufactured or reproducible capital, includes physical infrastructure, land, property, and facilities of private firms, houses, etc. Upon calculation, we follow the method conceptualised by Harberger (1978) and applied by King and Levine (1994) and Feenstra et al. (2013). Specifically, we employ the perpetual inventory method (PIM), which is a simple summation of gross investment net of depreciation that occurs in each period. One cannot keep track of investment and depreciation indefinitely into the past, so one should start from somewhere. This is called a benchmark year t = 0, in which the initial capital stock K(0) is set. Formally, produced capital stock at t is:

$$K(t) = K(0)(1-\delta)^t + \sum_{\tau=1}^{t} I(\tau)(1-\delta)^{t-\tau},$$

where $I(t)$ and δ stand for investment at t and depreciation rate. In our computation, the initial capital stock $K(0)$ is estimated by assuming a steady state of capital-output ratio. That is, if we assume $0 = \frac{d}{dt}\left(\frac{K}{y}\right) = (I - \delta K)/K - \gamma$ where γ is the economic growth rate, the steady state capital stock would be $K^{ss} = \frac{I}{\delta+\gamma}$.

Finally, it is worth noting that the shadow price of produced capital is unity, since national statisticians measure investment in produced capital in dollar terms, which is the unit of inclusive wealth. The dataset we employ is summarised in Table 1.

Table 1: Data sources and assumptions for the calculation of produced capital

Variables	**Data sources / assumptions**
Investment, I	United Nations Statistics Division (2013)
Output, y	United Nations Statistics Division (2013)
Depreciation rate, δ	4% (as taking the country average from Feenstra et al. (2013))
Capital lifetime	Indefinite

4. Human Capital

Investment in education pays off later in life through increased lifetime income and well-being, both at the individual and aggregate level. In line with the literature on human capital, and for practical reasons, we focus on the return on formal education, but this is not to imply that non-formal education (e.g., early childhood education, vocational training) does not contribute to wealth as well. We estimate the value of human capital on the output of the education production function. This is generally referred to as the income approach to human capital computation. In contrast, some other estimates use the input side of the education production function, typically by educational expenditure (World Bank 2014). For a more detailed account of this and an excellent review of human capital more broadly, see Chapters 3-4 of IWR 2014.

We estimate the value of human capital based on the idea that educational attainment yields return to human capital. Following Arrow et al. (2012) and Klenow and Rodriguez-Clare (1997), educational attainment is proxied by the average number of years of total schooling per person, A, which is obtained from Barro and Lee (2015). The rate of return on education is assumed to be constant at ρ =8.5%. This is multiplied by the population who has had education, P_{5+edu}. Thus, the stock of human capital is:

$$H = e^{\rho A} * P_{5+edu}$$

The shadow price of one unit of human capital is calculated by taking the present value of lifetime income, which is proxied by the average compensation to employees, w, per unit of human capital, times the expected working years, T. This brings us to the following formula:

$$p_H(t) = \int_0^{T(t)} w(\tau) e^{-\delta\tau} d\tau$$

The dataset we employ is summarised in Table 2.

Table 2: Data sources and assumptions for the calculation of human capital

Variables	**Data sources / assumptions**
Educational attainment, $\boldsymbol{A}$	Barro and Lee (2015)
Population $\boldsymbol{P}$ by age, gender, time	United Nations Population Division (2016)
Interest rate, $\boldsymbol{\rho}$	8.5% (Klenow and Rodríguez-Clare 1997)

Discount rate, $\boldsymbol{\rho}$	8.5%
Employment	International Labour Organization (2015); Conference Board (2016)
Compensation of Employees	United Nations Statistics Division (2016); OECD (2016); Feenstra et al. (2013); Lenzen et al. (2013); Conference Board (2016)

5. Natural capital

For natural capital, the current edition of the IWR accounts for non-renewable resources (fossil fuel and mineral) and renewable resources (agricultural land, forest, and fishery). We illustrate how we account for these five classes in turn.

5.1 Non-renewables

5.1.1 Fossil fuels

Our accounting scope for fossil fuels includes coal, natural gas, and oil. For a given resource, we start from the current stock, and then trace back past stocks by using the production of each year. In this way, we can construct a consistent time-series dataset that reflects more recent and accurate flow (extraction) variables. In other words, the corresponding stock under study in year $t-1$, $S(t-1)$, is derived from the production, $P(t)$, and the stock in year t, $S(t)$, by:

$$S(t-1) = S(t) + P(t).$$

The unit shadow price of a non-renewable resource, p_S, is the net price of extraction cost, which is sometimes referred to as the rental price. Ideally, the marginal cost of extraction should be used for the corresponding remaining stock, but it is known to be hard to obtain. We instead assume that the rental rate of the total price is constant, which is obtained from Narayanan et.al. (2012). The dataset we employ is summarised in Table 3. Figure 3 represents the composition of fossil fuels.

Table 3: Data sources and assumptions for the calculation of fossil fuels

Variables	Data sources / assumptions
S: reserve	U.S. Energy Information Administration (2015)
P: Extraction	U.S. Energy Information Administration (2015)
Prices	BP (2015) • Coal: averaged prices from U.S, northwestern Europe, Japan coking, and Japan steam • Natural gas: averaged prices from EU, UK, US, Japan, and Canada • Oil: averaged prices of Dubai, Brent, Nigerian Forcados, and West Texas Intermediate • adjusted for inflation before averaging over time using the U.S. GDP deflator
Rental rates	Narayanan et al. (2012)

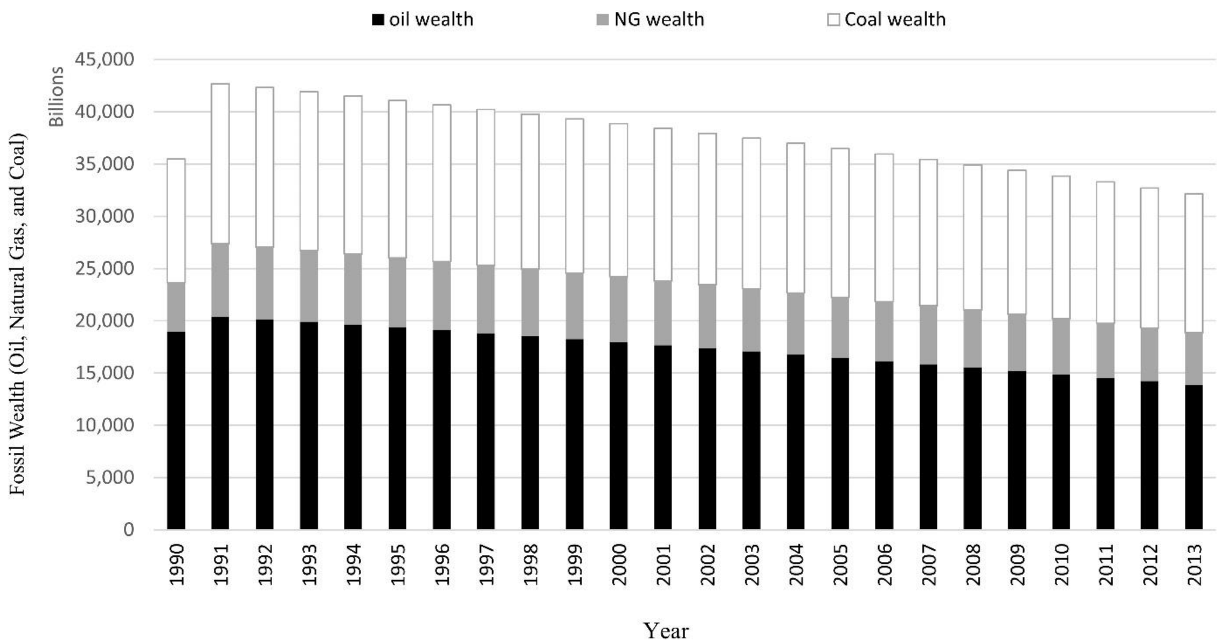


Figure 3: Composition of fossil fuel wealth from 1990 to 2013

5.1.2 Metals and minerals

The methodology for accounting for minerals is much the same as fossil fuels. For rental rates, we retrieved sectoral rental rates of different mineral industries from Narayanan (2012). For other data of reserves, extraction and prices are obtained from the U.S. Geological Survey (2015), which is the most authorised dataset on the subject. The dataset we employ is summarised in Table 4.

Table 4: Data sources and assumptions for the calculation of metal and mineral resources

Variables	Data sources / assumptions
$\boldsymbol{S}$: reserve	U.S. Geological Survey (2015)
$\boldsymbol{P}$: Extraction	U.S. Geological Survey (2015)
Prices	U.S. Geological Survey (2015)
Rental rates	Narayanan et al. (2012)

5.2 Renewables

5.2.1 Agricultural land

Agricultural land refers to cropland and pastureland. The methodology for accounting for these two classes is much the same. For quantifying this type of natural capital, permanent cropland/pastureland area data from Food and Agricultural Organization (FAO 2015a) is employed.

To quantify the marginal shadow price of a unit of agricultural land, we cannot use the market price as we do for non-renewable resources, since there does not usually exist a market for agricultural land. Instead, we compute the shadow price as the net present value of the annual flow of services per hectare that the parcel yields, in line with World Bank (2011) and past editions of IWR. More specifically, rental price per hectare of cropland for country i in year t can be expressed as:

$$RPA_{it} = \left(\frac{1}{A}\right)\sum_{k=1}^{N} R_{ik}P_{itk}Q_{itk}$$

where A, R, P and Q are the harvested area in crops, rental rate, crop price, and crop quantity produced, respectively. N stands for the number of crops, which is as many as 159 (k = 1, … , 159) in the current study. t is the year of analysis, from 1990 to 2014. For the estimation of the rental rate by crop group, we mapped FAO crop classification (HS) with those sectoral rental rates provided by Narayanan et al. (2012).

Note that the above rental price corresponds to an annual flow of services; we need to capitalise it to be employed as the shadow price. Formally, the NPV of this rental price for country i in year t is written as:

$$p_{Ait} = \sum_{\tau=0}^{\infty} \frac{RPA_{it}}{(1+r)^{\tau}} = \frac{1+r}{r} RPA_{it},$$

where r is the discount rate, set at 5% per annum. Finally, to avoid unnecessary volatility in the social value of natural capital, we take the year average of this price for country i:

$$\overline{p_{Ai}} = \frac{1}{25} \sum_{t=1990}^{2014} p_{Ait}$$

which is used as the shadow price of cropland.

For the calculation of pastureland wealth, the difference from cropland lies in the fact that it is difficult to link rents to a particular amount of land involved in the production process. Thus, we opted to assume the shadow price of pastureland to be equal to cropland, which is a limitation of the current accounting. The dataset we employ is summarised in Table 5. Figure 4 represents the composition of the agricultural wealth.

Table 5: Data sources and assumptions for the calculation of agricultural land

Variables	**Data sources / assumptions**
Quantity of crops produced, $\boldsymbol{Q}$	FAO (2015a)
Price of crops produced, $\boldsymbol{P}$	FAO (2015a)
Rental Rate, $\boldsymbol{R}$	Narayanan et. al. (2012)
Harvested area in crops, $\boldsymbol{A}$	FAO (2015a)
Discount rate, $\boldsymbol{r}$	5%
Permanent cropland/pastureland area	FAO (2015a)

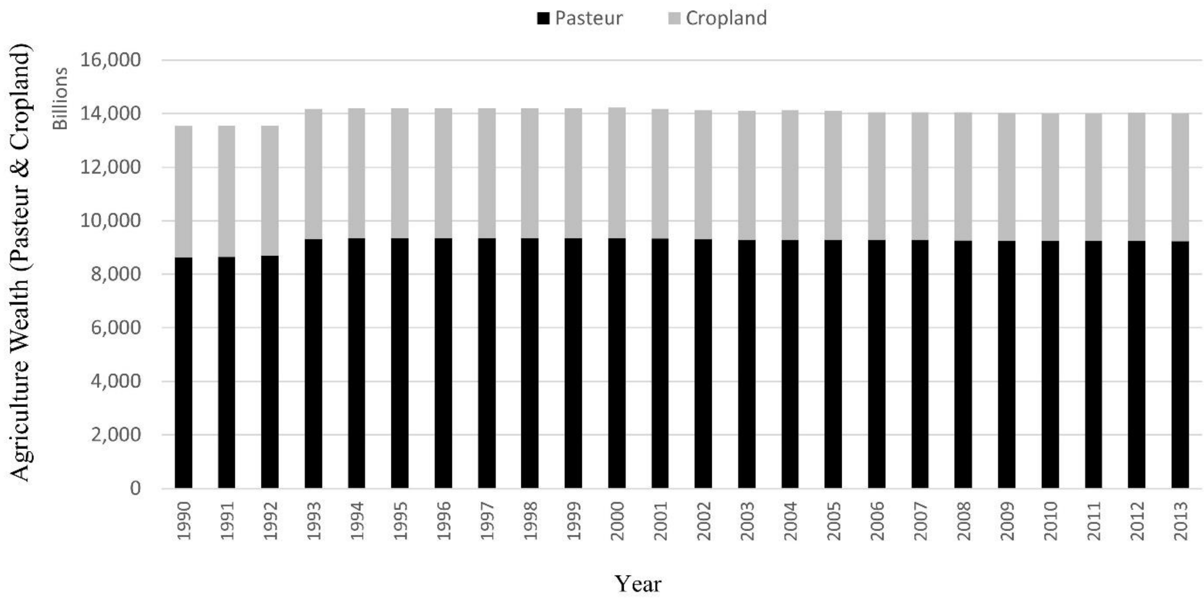


Figure 4: Composition of agricultural wealth

5.2.2 Forest

In the current forest accounting, we follow IWR 2014 methodology. The forest wealth is composed of timber value and non-timber forest benefits (NTFB).

Timber

We estimate the volume of timber resources commercially available. To estimate the quantity of this capital, the total forest area (excluding cultivated forest) is multiplied by timber density per area, and the percentage of total volume that is commercially available. The exclusion of cultivated forest could be debatable, as it is regarded as contributing to timber and non-timber value. It is excluded here because the activity of cultivating forest is categorised as a production activity in the System of National Accounts. In line with this reasoning, we have registered cultivated forest under produced capital in IWR 2014 and 2018.

Following IWR 2014, there are several steps involved in the computation of shadow prices. First, we employed the World Bank's (2006) method of adopting a weighted average price of two different commodities: industrial round wood and fuelwood, which are country-specific parameters. The weight attached to the different prices is based on the quantity of the commodity manufactured, while industrial round wood and fuelwood prices are obtained from the value and quantity exported and produced, respectively. Second, we converted the annual estimated values from current to constant prices by using each country-specific gross domestic product (GDP) deflator. Third, we used information on the regional rental rates for timber estimated by Bolt et al. (2002). Such rates are assumed to be constant over time. Fourth, we estimated the average price over the entire study period (1990 to 2014), thereby obtaining our proxy value for the shadow price of timber.

Finally, in the same manner as other resources, wealth corresponding to timber value is calculated as the product of quantity, price, and average rental rate over time. The dataset we employ is summarised in Table 6.

Table 6: Data sources and assumptions for the calculation of forest resources

Variables	**Data sources / assumptions**
Forest stocks	FAO (2015; 2010; 2006; 2001; 1995)
Forest stock commercially available	FAO (2006)
Wood production	FAO (2015)
Value of wood production	FAO (2015)
Rental rate, $\boldsymbol{R}$	Bolt et al. (2002)

Non-timber forest benefits (NTFB)

Aside from provisioning services in the form of timber production, forest capital yields many ecosystem services. Following IWR 2014, we have accounted for these non-timber forest benefits in the following manner.

First, total forest area in the country under analysis excluding cultivated forest is retrieved from FAO (2015b), which we denote by Q (ha). Second, the fraction of the total forest area which is accessed by individuals to obtain benefits is assumed to be γ. The ecological literature has stressed that only the portion of the forest that contributes to well-being should be accounted for. For want of better assumptions, we assume γ to be 10%, following World Bank (2006).

Third, the unit benefit of non-timber forest to intertemporal social well-being is taken from the Ecosystem Service Valuation Database (ESVD) of van der Ploeg and de Groot (2010). We denote this by P (USD/ha/year). The average value per hectare should be different for temperate and boreal, and tropical forest, as shown in Table 7. Accordingly, we weighted the corresponding values by the share of each forest type in the total forest of the country.

Fourth, to make this benefit into capital asset value, we take its net present value, using the discount rate of r=5%. In short, the value of NTFB forest wealth is calculated as,

$$\sum_{\tau=t}^{\infty} \frac{PQ_\tau \gamma}{(1+r)^{\tau-t}} = \frac{1+r}{r} PQ\gamma.$$

The dataset we employ is summarised in Table 7 from van der Ploeg and de Groot (2010). Figure 5 represents the composition of forest wealth.

Table 7: Accounting of non-timber forest benefits

Select service	**Temperate and boreal Forests (USD/yr/ha)**	**Tropical forest (USD/yr/ha)**
Provisioning services		
1 food	23	107
2 water	146	137
3 genetic	2	451
4 medical		475
5 raw materials		
6 ornamental		
Regulating services		
7 air quality	868	223
8 climate		
9 extreme events	0	33
10 water flows	2	14
11 waste	40	343
12 erosion	1	342
13 soil fertility	37	129
14 pollination	418	54
15 bio control	20	13
Habitat services		
16 nursery		17
17 genepool	506	396
Cultural services		
18 aesthetic		
19 recreation	27	257
20 inspiration	0	
21 spiritual		
22 cognitive	0	
Total	2,091	2,990

Source: van der Ploeg and de Groot (2010).

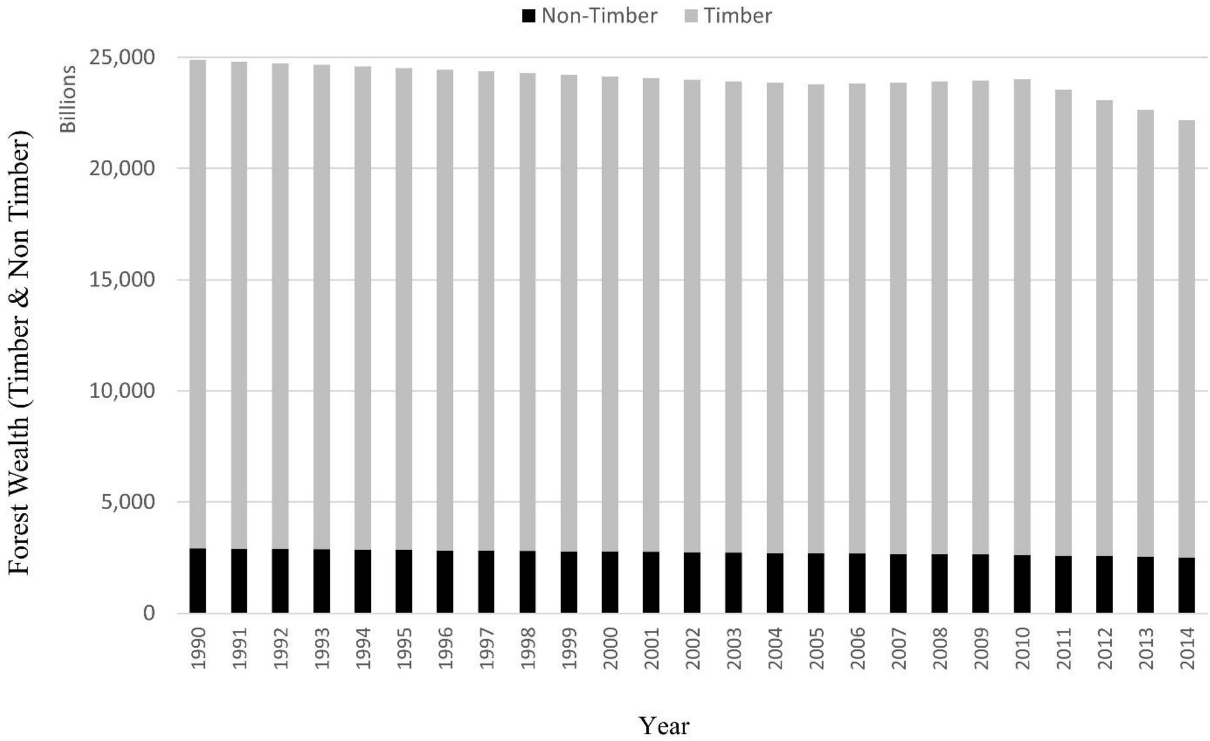


Figure 5: Composition of forest wealth

5.2.3 Fisheries

Estimating fish stock is a herculean task compared to other classes of natural capital, for many reasons. They cannot be estimated based on the habitat area, unlike forest or agricultural land, whose computation can be based on the area. Moreover, the sheer mobility of the resource not only makes the exercise harder but also poses a fundamental question: what area is a certain fishery attributed, given that a marine fishery habitat is usually not within national borders? In the current exercise, we simplify the matter by assuming that the fish stock belongs to the country where harvest takes place and the resources are loaded. Of course, this is a crude treatment in many ways: just because fishery biomass is loaded to a particular country does not necessarily mean that the fishery belongs to that country. Having acknowledged this shortcoming, we have no available alternative to allocate harvests to countries. In what follows, our estimates of the fishery wealth of nations should be interpreted as capital stocks that exist in the fisheries operating in these countries.

In renewable resource economics, or bio-economics, there is a long tradition of assuming resource dynamics (Clark 1976/1990). The stock is the population growth net of harvest:

$$\frac{dS_t}{dt} = G(S_t) - H_t,$$

where S_t denotes the renewable resource biomass stock; $G(S_t)$ is the growth function; and H_t is the harvest. The population, whether it refers to a renewable resource or human beings, is often assumed to follow a logistic growth function:

$$G(S_t) = rS_t\left(1 - \frac{S_t}{k}\right),$$

where r and k are the parameters that represent the intrinsic (relative) growth rate and carrying capacity of the resource stock, respectively. The harvest, in turn, depends on the resource abundance. A simple but empirically supported harvest production function is to assume that it is proportional to the product of effort and stock, i.e.,

$$H_t = qE_tS_t,$$

where q is the catchability coefficient. E_t stands for the effort put into the production process, which is often proxied by the number of vessels or fishermen's working hours. Combining these two equations, we obtain a familiar Gordon-Schaeffer model:

$$\frac{dS_t}{dt} = rS_t\left(1 - \frac{S_t}{k}\right) - qE_tS_t.$$

This means that to estimate the fishery stock, S_t, we can resort either to the harvest function (1), or total resource dynamics (2). Global fish stocks are commonly assessed by examining the trends in catch or harvest data. Although this catch-based assessment method has attracted significant criticism (see, for instance, Daan et al. (2011)) due to its technical and conceptual flaws, it is still considered the most reliable method for assessing fish stock (Froese et al., 2012; Kleisner et al., 2013). The main reason is simply that the only data available for most fisheries are the weight of fish caught each year (Pauly et al., 2013). If data points for effort and harvest are available as well as the catchability coefficient q, then S_t can be estimated solely from the Schaefer production function (Yamaguchi et al. 2016). This estimation considers the Gordon-Schaefer model of fishery biomass stock:

$$B_{t+1} - B_t = rB_t\left(1 - \frac{B_t}{k}\right) - C_t$$

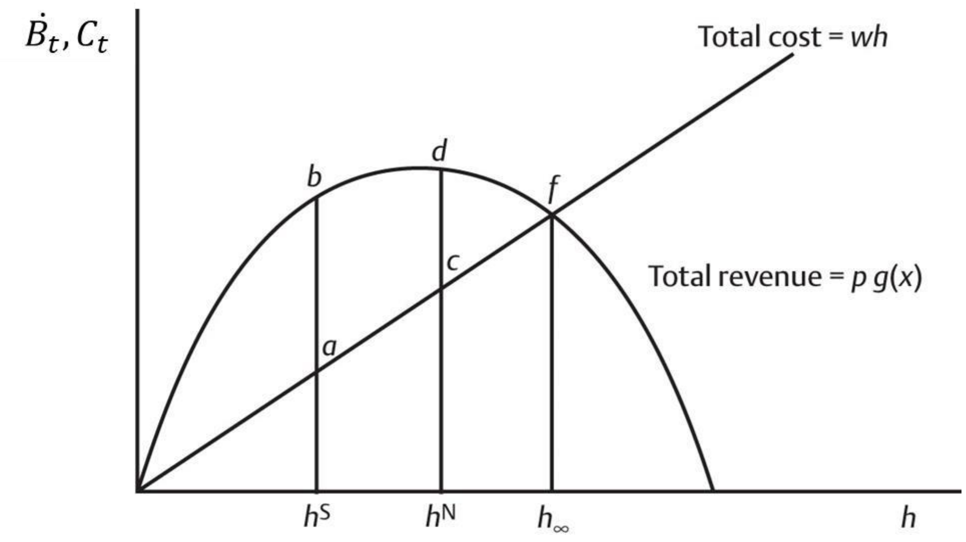


Figure 6: Fishery biomass stock

However, effort data are sparse worldwide, so we cannot employ this method for inclusive wealth accounting across the globe. Alternatively, we can appeal to resource dynamics. For the lack of reliable data on r and k for most fish stocks, we follow Martell and Froese (2013), who developed an algorithm to randomly generate feasible (r, k) pairs from a uniform distribution function. The likelihood of the generated (r, k) pairs is further evaluated using the Bernoulli distribution to ensure that the estimated stock meets the following assumptions: it never collapsed or exceeded the carrying capacity, and the final stock lies within the assumed range of depletion.

In cases where the values of (r, k) are not feasible, the stocks were simply estimated according to the following:

- If the year being studied follows the year of the maximum catch, then the biomass stock is estimated as twice the catch;
- Otherwise, the biomass stock is estimated as twice the maximum catch, net of the catch (2 x Maximum Catch – Catch).

The time series data of the catch (tonnage and value) of each country's economic exclusive zone (EEZ), either by domestic or foreign fleets, for the period of 1950-2010 are obtained from the Sea Around Us Project (SAUP 2016). We only evaluate the stock with a catch record of at least 20 years and which has a total catch in a given area of at least 1000 tons over the time span.

The shadow prices of fisheries, like other classes of natural capital, ideally reflect their marginal contribution to social well-being. More specifically, they represent not only their marginal abundance but the substitution possibilities with other capital forms (Dasgupta 2009). In a case study of predator-prey dynamics in a Baltic Sea commercial fishery, Yun et al. (2017) showed that the shadow prices of species are interdependent on relative abundance and scarcity, in a multispecies ecosystem-based management context. Applying a similar methodology to our current natural capital estimate would need a much more detailed dataset than ours. Moreover, there is an obvious tradeoff between disaggregated, state-dependent shadow prices, and the clarity of accounting. For example, if we attach shadow prices that differ according to countries, species, cohorts, years, etc., it would be difficult to disaggregate the reason for the change in the value of capital stocks, although this may be resolved by advancing the way the figures are presented. Additionally, the period-average shadow prices, which are adopted elsewhere in IWR, can be shown to be justified as a good approximation, either in a short period of time or the shadow price change is linear in time. Thus, currently, we choose to use a simple unit market rent that reflects a period-average, species average market price adjusted by the rental rate.

For policy purpose, we obtain a 20-year forecast from our models. For this purpose, we use the world population prospect of the United Nations to obtain the projected global population of 2030. We also assume that the global economy grows at a constant rate of 2.6 percent per annum.

A more detailed analysis of the top fishing countries examined (see Figure 7) shows that rich countries such as Japan, the UK and the USA contribute positively to declining global catch levels, which in turn prevent the stock from deteriorating further. This highlights the beneficial impacts of better fisheries management systems used in these countries. Interesting findings were observed in the case of Malaysia. Unlike those of other middle-income countries, Malaysia’s total catch is expected to peak in the near future. However, such declining catch levels are not immediately followed by stock recovery. For other developing countries such as China and Indonesia, we expect to see an increase in catch levels over the next two decades, leading to a steady decline in stock levels.

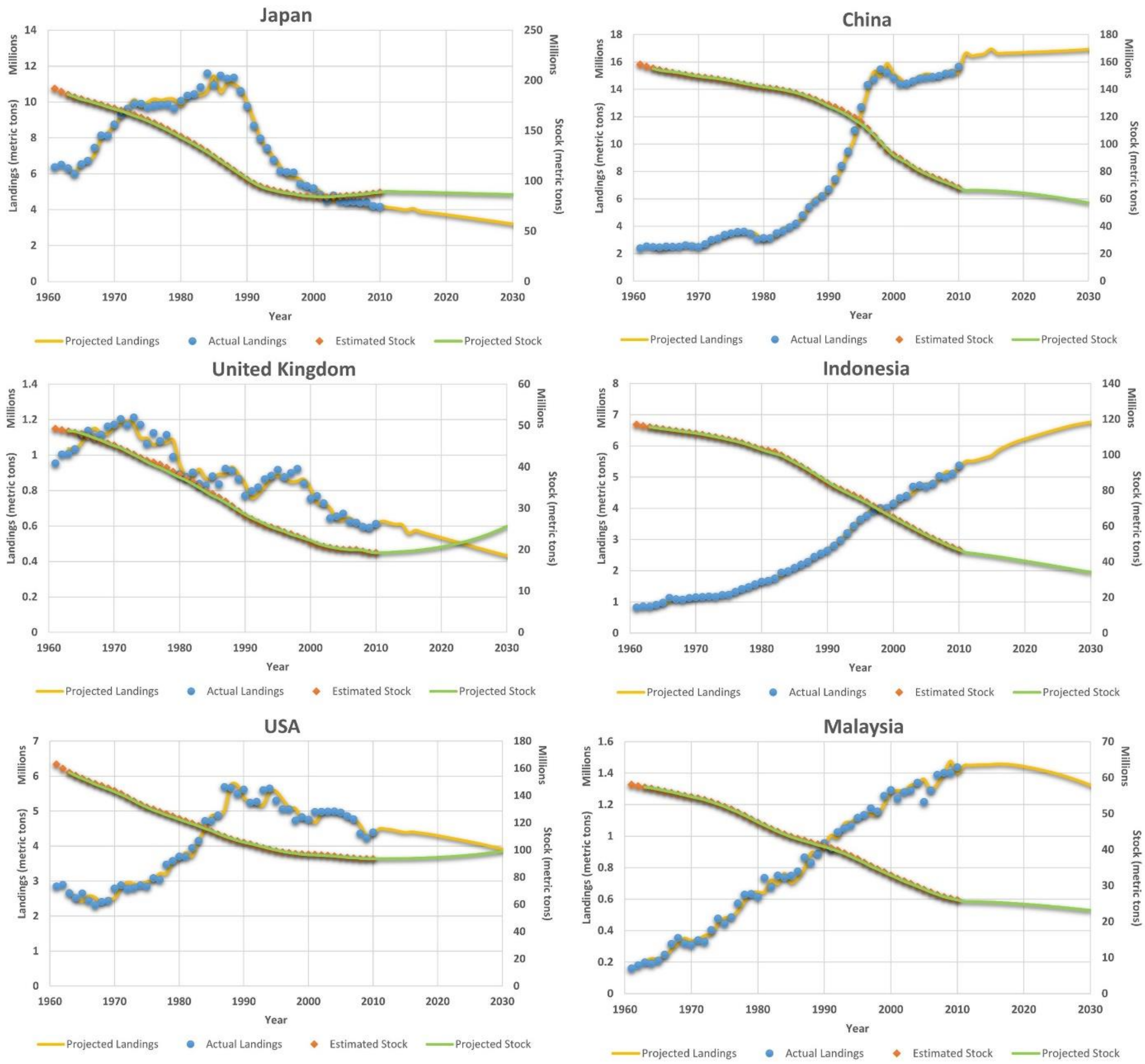


Figure 7: Projection of landings and stocks for the examined countries

We forecast that over the next two decades, global catch levels should decline alongside economic and population growth. We also expect to find a slight decline in stock levels followed by indications of stock recovery. However, our models do not dismiss the need for more stringent environmental regulations and for the use of better fisheries management practices. The higher secondary turning point and the small value of the lagged error-correction term of the biomass model suggest that current quota-based management approaches that attempt to limit catch values might help mitigate pressures on the environment while preventing stock depletion. However, stock recovery is unlikely to be observed over the short-term.

6. Adjustments

We treated three adjustments that are not covered by familiar capital assets that however contribute to social well-being change: carbon damage, oil capital gain, and total factor productivity. We essentially follow IWR 2014 methodology for these adjustments.

6.1 Carbon damage

Following Arrow et al. (2012), we can think of carbon damage as a mostly exogenous change in social well-being, as this does not correspond to each country's emissions. As in IWR 2014, the key methodological steps can be described as follows:

(1) Obtain the total global carbon emissions for the period under analysis, 1990 to 2014;

(2) Derive the total global damages as a function of the emissions; and,

(3) Allocate the global damages to the countries according to the potential effect of global warming in their economies.

1) Global carbon emissions: Two sources of carbon emissions were taken into account: (i) carbon emissions stemming from fuel consumption and cement, which were obtained from the Carbon Dioxide Information Analysis Center (Boden et al. 2011); and (ii) emissions resulting from global deforestation. In this case, we used FAO (2013) data on the changes in annual global forest land. It is further estimated that the average carbon release per hectare is equal to 100 tonnes of carbon (Lampietti and Dixon 1995).

2) Global carbon damages: The damages per tonne of carbon released to the atmosphere are estimated at US$50 (see Tol 2009). By multiplying the total amount of global tons of carbon released to the atmosphere by the price per ton, we obtain the total global carbon damages. Note that this parameter is constant over time.

3) Assigning carbon damages to countries: To calculate the distribution of the damages that each region suffers, we referred to a study by Nordhaus and Boyer (2000). This study presents the distribution of damages incurred by different regions and the global economy as a percentage of the corresponding regional and global GDP. By using country and global GDP information, we were able to re-estimate regional percentage damages in terms of the total global GDP – and not related to the country GDP – as initially presented in Nordhaus and Boyer (2000). Finally, we apportioned the global damages estimated in previous steps two according to this latter percentage.

In figure 8, we show the global trend of natural capital and CO2 emission damages. It is clear that the damages are increasing consistently from 1990 to 2014, while the natural capital stock is sharply declining. Figure 9 describes the steps of calculating the carbon damages in countries. Figure 10 shows the relationship between natural capital per capita and CO2 emissions per capita, by country in 2014. We have separated the relationship for four income categories and notice that in every category, there are some outlier nations which are producing high CO2 emissions per-capita but have low natural capital per capita.

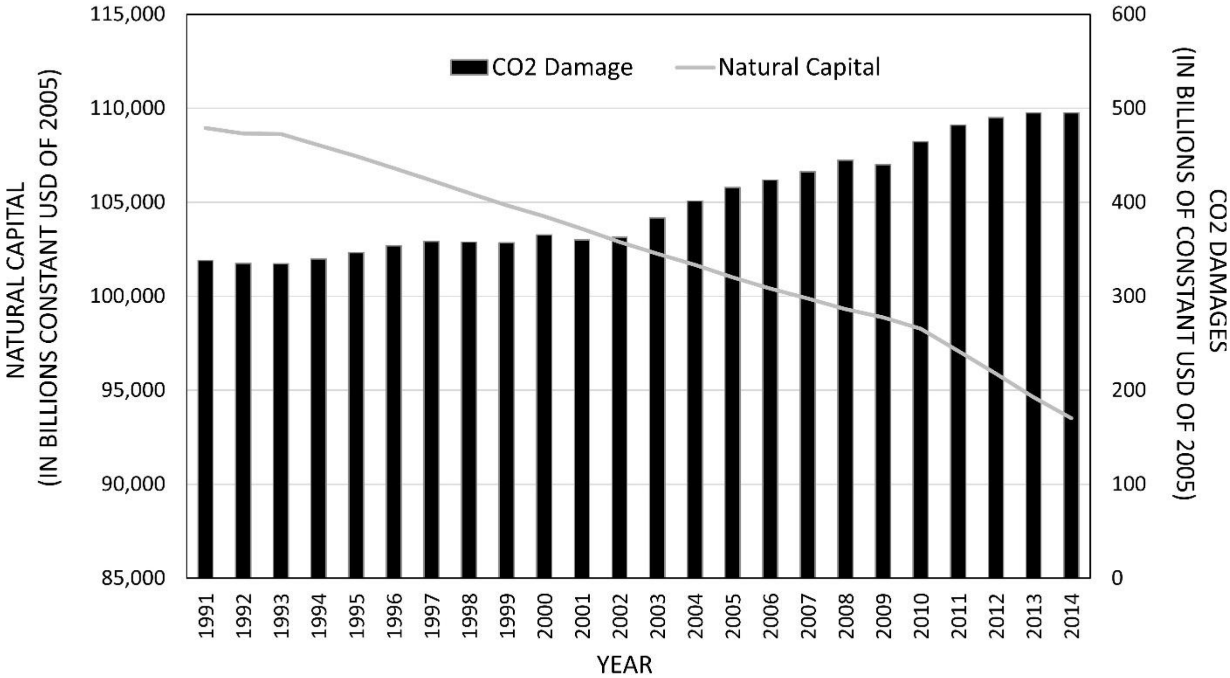


Figure 8: Trends in global natural capital and CO2 emission damage over time

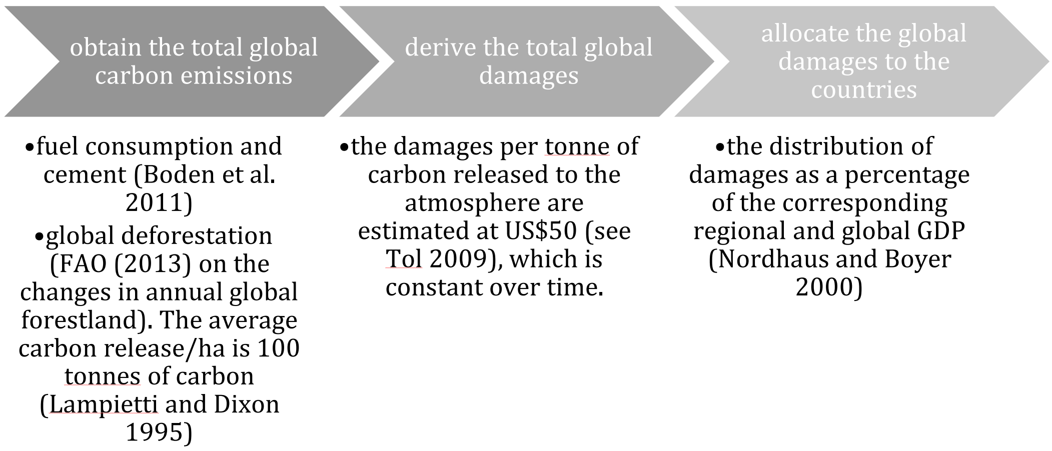


Figure 9: Carbon damages

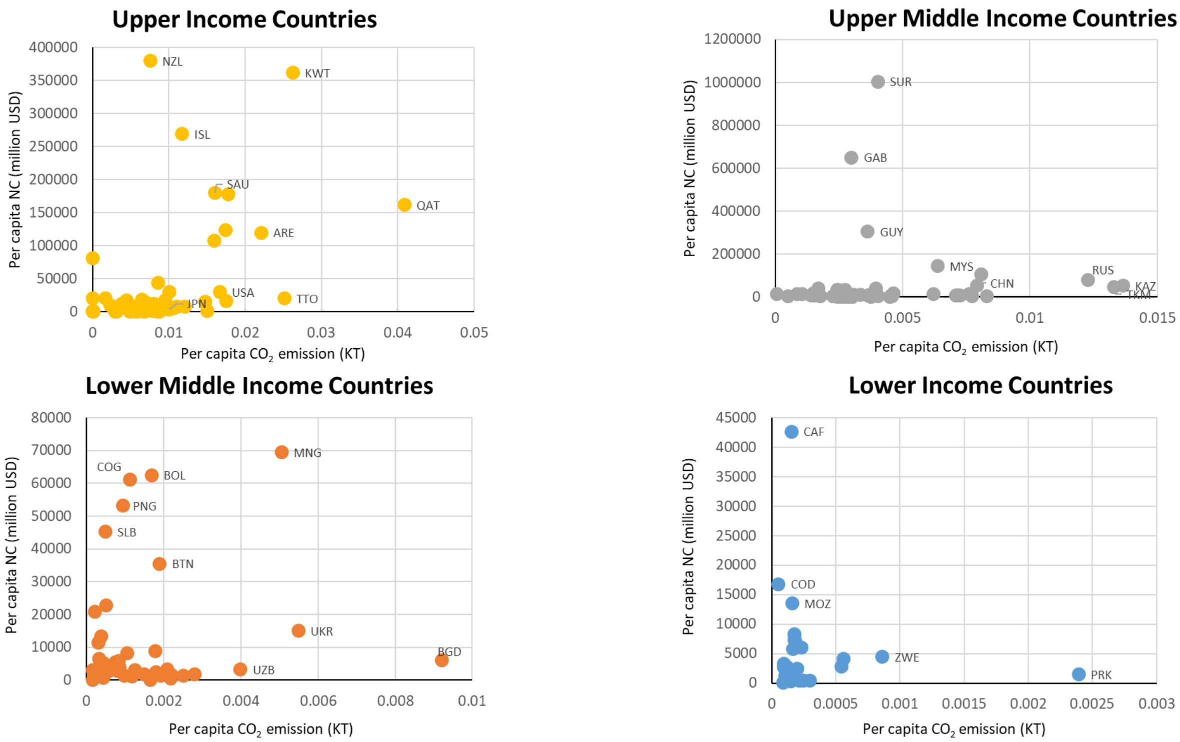


Figure 10: Natural capital per capita and CO2 emissions per capita by countries in 2014

6.2 Oil capital gain and loss

- If oil price goes up, oil-rich nations enjoy an increase in wealth. An annual increase of 3% in the rental price of oil is assumed, which corresponds to the annual average oil price increase during 1990-2014 (BP 2015).
- Conversely, importing-countries may have fewer investment opportunities due to higher oil prices, so oil capital losses are distributed to consuming countries.

Figure 11 shows the annual average increase in oil price since 1976 to 2014.

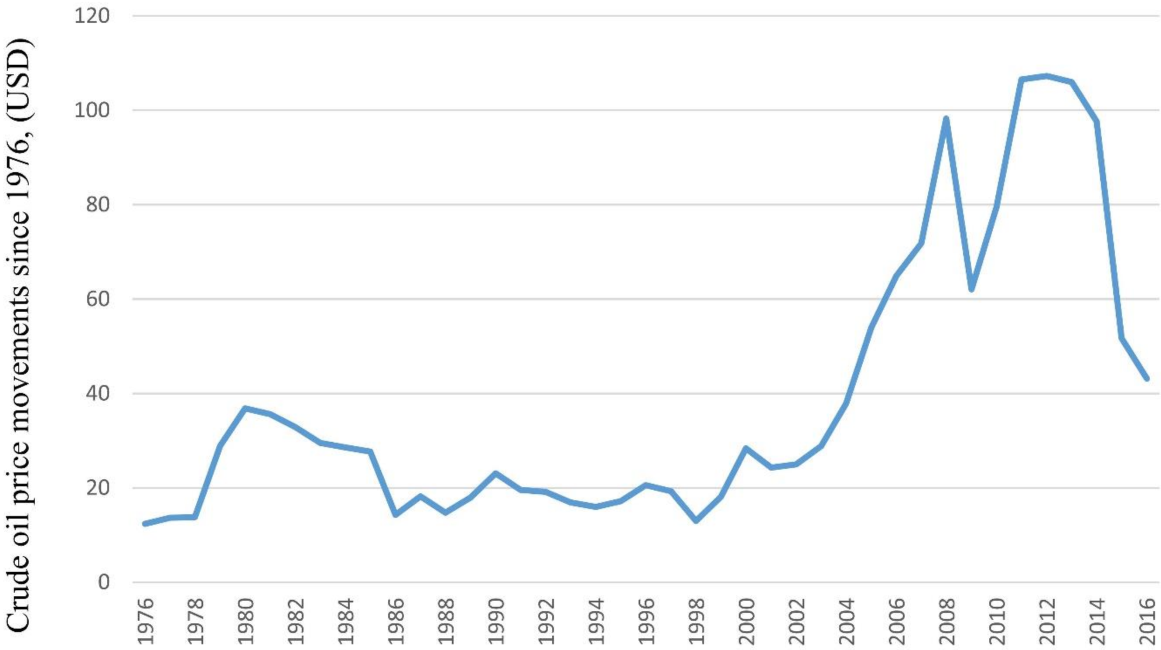


Figure 11: Annual average oil price increase (Source: BP 2015)

6.3 Total factor productivity

Total factor productivity (TFP) of a nation is a type of resource that can be accessed, even though they are intangible. We use the TFP data calculated conventionally by Conference Board (2017), in line with Arrow et al. (2012) and IWR 2012.

To provide estimates following other methodological approaches, we also take a different method in computing and comparing the TFP. We used a non-parametric analysis called Malmquist productivity index, which in turn is based on the concept of data envelopment analysis.

For frontier analysis, let

- x_t: Inputs (produced, human, and natural capital)
- y_t: Outputs (GDP)
- Distance function: $d(x_t,\ y_t) = \max\{\delta; (x_t,\ y_t\ |\delta) \in T(t)\}$
- Malmquist Productivity Index $M(Y_{it}, K_{it}, H_{it}, N_{it}, Y_{it+1}, K_{it+1}, H_{it+1}, N_{it+1})$

$$= \left[\frac{d^t(Y_{it+1}, K_{it+1}, H_{it+1}, N_{it+1})}{d^t(Y_{it}, K_{it}, H_{it}, N_{it})} \times \frac{d^{t+1}(Y_{it+1}, K_{it+1}, H_{it+1}, N_{it+1})}{d^{t+1}(Y_{it}, K_{it}, H_{it}, N_{it})}\right]^{\frac{1}{2}}$$

where *d* is the geometric distance to the production frontier caused by production inefficiency, while the frontier denotes the best available technology from the given inputs and outputs. i

refers to the country under analysis, running i from 1 up to 140 nations in our sample; Y is the corresponding value of gross domestic product; K, H and N stand for produced, human, and natural capital inputs.

Arrow et al. (2004; 2012) suggested that total factor productivity (TFP) can contribute to social well-being through three-capital changes. Formally, TFP can be regarded as shadow value of time as a capital asset (UNU-IHDP and UNEP, 2012). IWR thus includes the change in TFP as an adjustment term, based on the finding that we need merely to add TFP growth to inclusive investment (Arrow et al., 2012). *A* in the production function *A(t)F*(K(*t*)), where K(*t*) is the vector of capital assets and *F*(*.*) is the constant-returns-to-scale production function, can be interpreted to be an aggregate index of knowledge and the economy's institutions. In conventional growth accounting, K(*t*) includes produced and human capital. In a remarkable move to include natural capital in growth accounting, however, Vouvaki and Xepapadeas (2009) observe that dismissing natural capital can mislead the analyst to interpret degradation of the environment as an improvement of knowledge and institutions. Brandt et al. (2013) argued that failing to account for natural capital tends to lead to a biased estimation of productivity growth. Natural capital has also remained largely hidden to policymakers due to the limitations of traditional economic indices (Fujii and Managi, 2013; Managi et al., 2004; Johnstone et al., 2017; Kurniawan & Managi, 2017).
In this report, therefore, we calculated TFP as a residual by expanding natural capital (forest, agriculture land, fish, fossil, and minerals) as an explicit factor of input into the production process. By integrating natural capital, we can understand that the same productive base of a country may lead to an increase (decrease) in aggregate output over time regarding the effective utilisation of its productive resources. In particular, the frontier approach in IWR 2018 measures TFP adjustment by capturing the efficient utilisation of natural capital, as well as produced and human capital, by using the Malmquist Productivity Index approach. The result shows that 55 of the 140 countries – more than one third of our sample – show a negative average TFP. Increasingly, investments in R&D tend to be focused on areas revolving around produced and human capital, but we need to shed a new light on ways to efficiently employ natural capital and the environment in the modern economy. This brings us to the question of how environmental policy can actually improve productivity.

Porter and van der Linde (1995) postulated an apparent link between productivity and environmental policy. According to their hypothesis, well-designed environmental regulation can provide "a free lunch" and can trigger innovation, which in turn, can decrease and offset the costs of pollution abatement and enhance competitiveness. New evidence from the OECD countries shows that increasingly stringent environmental policies of recent years have had no negative effect on overall productivity growth (Ambec et al., 2013). The researchers found that before tighter environmental policies came into effect, the overall productivity growth of a country slowed, possibly because firms anticipated the changes and prepared themselves for new operating conditions. However, a rebound in productivity growth soon followed, with no cumulative loss reflected in the data. Lanoie et al. (2008) also found a positive relationship between lagged regulatory stringency and productivity; innovations may take several years to develop, and capital expenditures are often delayed for a few years through normal budgetary cycles and building lags.

These results imply that more stringent environmental policies, when properly designed, can be introduced to benefit the environment with no loss of productivity. Well-designed market-based instruments, such as taxes on externalities or cap-and-trade schemes, score better in dynamic efficiency than environmental standards and effectively induce broadly defined innovation, providing firms more flexibility in the way they adapt to new environmental policy (De Serres et al., 2010). Global society is required to innovate environmental practices based on incentives for industries to perform well in their environmental management and formulate economic and environmental policies simultaneously to achieve the sustainability of the growth process.

Innovations have minor importance in sustainable development issues with respect to exploiting resources for production, consumption, and disposal by a better means. Thus, it has been pivotal to work toward a more advanced technological shift and shift in the progress up to this point, through the deployment of sustainable techniques and products (Hemmelskamp, 1999). Technology innovation and efficiency catch-up are driven by productivity growth. Consequently, environmentally friendly technologies, such as waste heat to electricity conversion, may lead to an improvement in productivity regarding which resources (energy) are used.

The widespread adoption of energy-saving technologies is necessary to have policy-induced impulses that help companies cope with the adoption barrier. With regards to energy efficiency, Jaffe and Stavins (1994) argued that several aspects of energy-efficient technologies are not widely used without policy inducement. Contributing factors include a lack of information about available technologies, (particularly when there are no incentives), principal/agent problems, low energy prices, and high implicit discount rates. The most powerful driver to support energy efficiency is an economical aspect; if an energy efficiency project shows promise to be profitable, there will be willingness to participate in the projects.

Investments in energy efficiency have many positive effects, not only an economic impact through maintaining energy security and increasing competitiveness but also environmental and health impacts through reducing GHG emissions. Arvanitis et al. (2016) proved a direct positive effect of investment spending for energy-related technologies on labor productivity and indirect positive effects of energy taxes through investments in energy-related technology. Thus, countries would do well to encourage more investment in the energy efficiency sector.

In the agricultural sector, public policies, such as investments in research extension, education and infrastructure, and natural resource management have been the major sources of TFP growth. Chand et al. (2011) found that public investment in research has significantly enhanced TFP growth in most crops. The variables for natural agricultural resource management and produced capital have been important sources of TFP growth for most crops. Among natural resources, a dependable supply of irrigation revealed by the proportion of groundwater in total irrigation, in addition to the balanced use of fertilisers, has played a significant role in increasing TFP. Investments in agricultural technologies, such as drought-resistant seed varieties, soil-improving technologies, and solar energy sources, are options that may further increase the productivity of the agricultural sector.

These results in conjunction with previous discussions provide several noteworthy contributions to policymakers. First, these findings enhance our understanding of how particular countries can measure and manage sustainability by incorporating natural capital into TFP. Second, countries need to develop well-designed environmental regulations to trigger innovation and utilise their productive assets in a more effective manner. Third, policymakers are encouraged to support the research and development of renewable resource technologies, although their impact on social well-being is yet to be captured. The contribution of investment in technology is crucial to confront the dwindling natural resources and to achieve the desired productivity growth in terms of social well-being.

7. Inclusive Wealth

Figure 12 shows how these three capitals lead to the ultimate objective — if any — of an economy: to promote social well-being. The three capitals are inputs into the production system; thus, they are called the *productive base* of the economy. Produced capital is the simplest to imagine: roads, ports, cables, buildings, machines, equipment, and other physical infrastructures. Human capital consists of population (size and composition), the knowledge and skills acquired by education, and health (enhancing quality of life, extending life, and boosting productivity). For natural capital, the current accounting addresses sub-soil non-renewable resources, forests, and agricultural land, but ideally it should also include ecosystems in general.

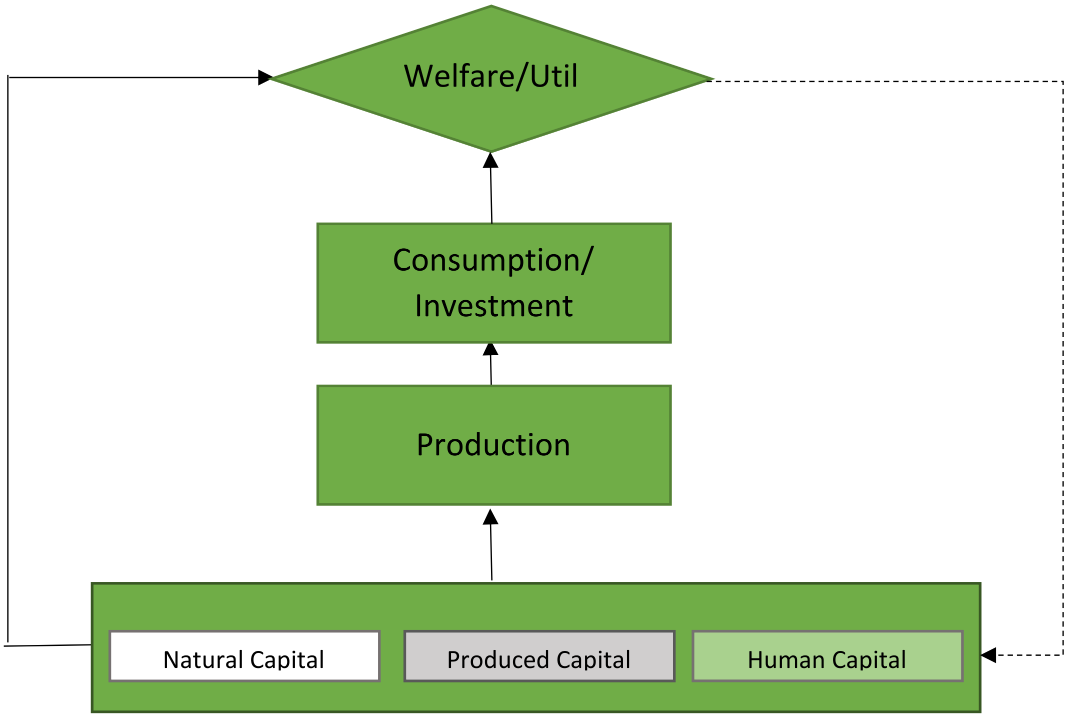


Figure 12: A three-capital model of wealth creation

Along with these three familiar capital assets, our first edition (UNU-IHDP and UNEP 2012) noted that knowledge, population, institutions, and even time can be conceived as capital assets. Dasgupta (2015) called them *enabling assets* in the sense that they enable the three capital assets to function well to improve social well-being. Formally, they could increase the shadow prices of pillar capital assets.

All in all, unconventional capital includes the following:

- Institutions (property rights, firms, government, households);
- Knowledge (natural laws, algorithms, theorems, cultural narratives);
- Social capital (the law, social norms, habitual practices); and
- Time (exogenous changes experienced by society over time).

While including these capital assets would be commendable, they are elusive as they currently stand. Changing institutions reveal themselves in how capital assets are employed to improve social well-being; thus, they could be a determinant of the shadow prices of capital assets. Time as an asset represents the value of waiting, including Solowian technological progress, resource price movements, population changes, and other exogenous shocks to the economy in question. The IWR 2014 and our edition of this IWR 2018 address all of these terms in the adjustment of IWI, namely population changes, total factor productivity (TFP), oil capital gains, and carbon damage. Thus, time as an asset is already addressed in our framework.

Once we establish relevant capital assets, then the output of this production process is either consumed or invested, as a result of national accounting identity. Current consumption directly improves current well-being, while investment increases the accumulation of productive base, which in turn improves future well-being. This fundamental tradeoff between consumption and investment has been a persistent problem of optimal saving, dating back at least to Ramsey (1928). However, in our context of sustainable development, economies should strike a balance between consumption and investment, the latter including the degradation — negative investment — of natural capital[4].

Some studies have suggested that there is a direct effect of capital stocks on utility, circumventing the consumption channel. For example, air pollution or climate change can cause disutility, for which increased consumption cannot be a substitute (Krautkraemer 1985; Xepapadeas 2005; d'Autume and Schubert 2008). It is not uncommon in climate change modeling to assume that climate directly affects utility (van der Ploeg and Withagen 2014). It is for these reasons that we present an alternative route from a productive base to welfare in Figure 12. The IWR 2018 method was improved in general following Managi, S. (2019, 2016, 2015a & 2015b). This report also captures the discussion of ecosystem services in Managi, S. (2012) and TFP concept discussed in Managi, S. (2011 & 2008).

It is imperative to note that the absolute value of wealth *per se* does not indicate anything meaningful. Only the comparison of wealth across time or space (nations) can have welfare significance. Asheim (2010) showed that net national product (NNP) per capita can be the most appropriate index for the purpose of welfare comparisons across different countries. In any case, we must resist the temptation to compare the absolute value of inclusive wealth (per capita); our interest should lie in the *change* in inclusive wealth per capita over the course of years. Figure 13 shows the inclusive wealth and the per capita inclusive wealth of the countries in the global average level.

[4] Hartwick (1977) and Dixit et al. (1980) showed that investing exhaustible resource rents into produced capital yields non-declining consumption, which is another way of defining sustainable development.

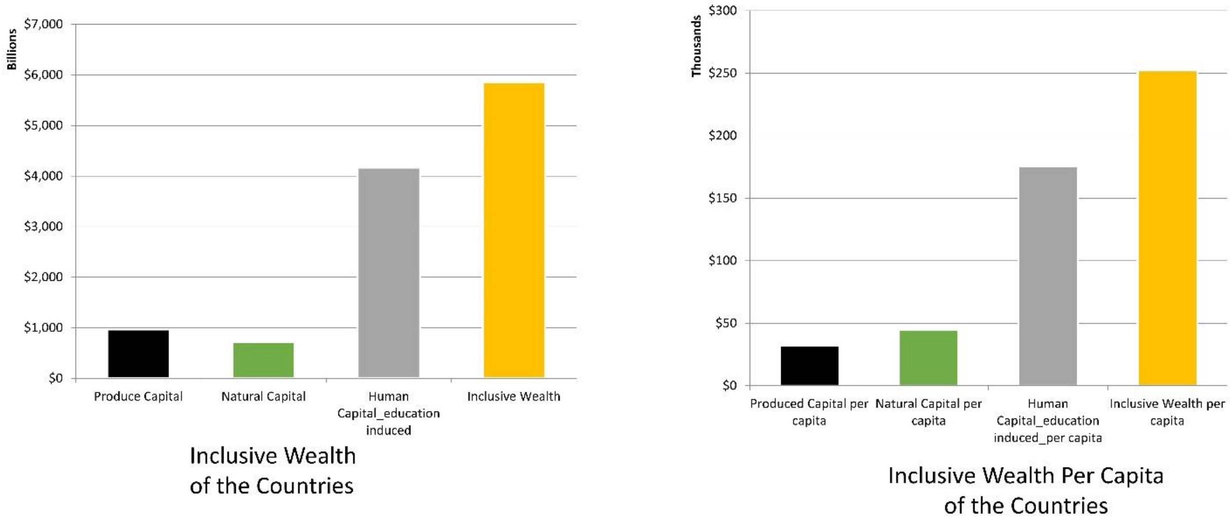


Figure 13: Global average Inclusive Wealth

Building on our first and second editions of IWR, this year's report features several advancements and expansions. First, our rich sample continues to track the 140-country sample of IWR 2014, compared with 20 countries (IWR 2012). The dataset now represents the lion's share of world GDP (56,835 billion) and of the global population (6,885 million).

Second, the studied time period is also expanded by five years to a quarter century which expands our coverage to the period of 1990-2014, providing us with a comprehensive picture of the changes in capital assets over almost an entire generation.

Third, our dataset of natural capital now includes one of the most significant renewable and mobile resources: fisheries. This inclusion adds to our list of renewable resource natural capital, which already included forest resources and agricultural land in IWR 2012 and 2014. IWR 2012 included some discussion of the fishery resources of no more than four countries for the time period of 1990–2006, based on studies of fishery stock (the RAM Legacy Stock Assessment Database (Ricard et al. 2012) and shadow prices (SAUP 2011). Our edition boasts a much more refined calculation of fish stocks and extends to include many countries.

We conclude by alluding to some of the major challenges and further potential discussions.

Completing the list of capital assets.

By construction, we are asked to account for many capital assets, provided that they affect intertemporal well-being and they do not overlap with existing capital assets. Otherwise, the very premise of an equivalent relationship between wealth and well-being would collapse[5]. We have included fish wealth as an important constituent of natural capital for virtually the first time. Another class of natural capital that arises as important to consider is water, which is vital to economies and people of all income categories. As was experimentally discussed in UNU-IHDP and UNEP (2012), water poses a challenge in terms of complex relationships between flow and stock variables[6]. In addition, the resilience of nature can be added as another essential capital to economies, at least conceptually (Mäler and Li 2010) and locally in practice (Walker et al. 2010). However, properly accounting for ecosystem resilience in a non-local manner would be difficult, if not impossible, given current available methodologies.

Furthermore, incorporating the value of institutions and social capital can present further challenges. Aside from their intangibility, part of the issue in accounting for these assets arises from their very nature: they enable other capital assets to function, to yield well-being (Dasgupta 2015). Therefore, we should resist the temptation to add, for example, social capital as another capital asset in an ad hoc manner, such as the valuation of social capital through revealed preference. A more promising method would be to account for social capital in a two-stage setup, in which we can see how social capital raises the shadow prices of other capital assets.

Shadow prices.

Even in imperfect economies, as we know, the relative weight of capital assets has been shown to be formalised as their marginal contributions to social well-being, given a forecast of an economy (Arrow et al. 2012), as we demonstrated in Section 2. In the current volume of IWR, we have demonstrated results in which non-parametric frontier analysis is used to compute the shadow prices of human capital. This approach comes with its costs: compared to the education approach to human capital shadow prices, GDP is used as the output, corresponding to the three capitals[7]. Inclusive wealth accounting for sustainability assessment

[5] If our list of capital assets is not complete, wealth could deviate from well-being. On an empirical level, there have been studies to test genuine savings and consumption changes (Ferreira et al. 2008; Greaseley et al. 2014), and we recommend similar studies be conducted for inclusive wealth as well.

[6] Fenichel et al. (2016) attempted to account for local groundwater in an imperfect economy. [7] One can defend the use of GDP as the output of three capitals by claiming that the value of life expressed as health capital implicitly nests future generations. However, this interpretation of utility function would be very limited, so we do not push this thesis any further.

is, by construction, founded on intertemporal well-being, so it would be best if we could use the latter as the output. Admittedly, the education approach is also not without shortcomings: the rate of return on education, as well as value of statistical life (VSL) year, is derived from market transactions and thus can deviate from the marginal impact on well-being. Perhaps of more concern to us in the face of looming climate change is the non-linearity of shadow prices. We are required to update our shadow prices, if necessary, once scientific evidence of the scarcity of the components of natural capital is revealed.

Coevolution and interdependence of capital assets.

The shadow price of a given capital reflects marginal social value, but it can also be subject to other capital assets. In the language of ecological economists, capital assets co-evolve. For example, we can think of negative externalities in health capital. We have already accounted for carbon damage by greenhouse gases in the adjustment terms, but it might also be a good idea to include local air pollution, as is performed for particulate matter in the World Bank's (2016) computation of genuine savings. Indeed, there is ample evidence that local air pollution, both indoor and outdoor, is hazardous to health and poses a hindrance to longevity. Local air pollution acts more like a flow variable rather than a stock, but it could be formalised as a persistent negative natural capital. Even so, care should be taken not to double-count health capital because if the VSL already captures shorter life years caused by air pollution, it would be redundant to account for its externality to health.

To provide another example, it is not necessarily clear to which capital urban land is allocated; currently, it is in many cases implicitly considered within produced capital. In its analysis of state-by-state wealth accounting, UNU-IHDP and UNEP (2012) has explicitly placed urban land under produced capital. Improving the amenity value of the environment in cities, therefore, could potentially boost the shadow value of urban land. Conversely, natural capital shadow prices could be affected by produced capital investment. However, this question remains open to discussion since it would involve consumers' surplus, which might not exactly match shadow value in inclusive wealth accounting. This consideration would bring us back to the matter of shadow prices.

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Appendix

The variables we employ are summarized in Table 8 and Table 9.

Table 1: Classification of main equations

Sl. No.	Variable	Symbol	Main Equation the Variable is Used In	Explanation Given in the Report	How does it impact the variables
1	Average life's working period	*T*	$SP_{HC\,(t)} = \int_0^{T_t} \bar{r}.e^{-\delta.t}.dt$	• Obtained using indicators such as population, labour force and mortality rates.	• Under Indirect control of the players (Countries) • Can be influenced by the decision countries take with respect to their: ○ Health Policies – health care services, Health Insurance ○ Hospitals incentivisation ○ Employment practices of Industry Players/ Industry lobbies ○ Labour policies implemented by the Government • All these are actions in the control of each country.

2	Investment	I	$k = \frac{I/y}{\delta + \gamma}$	• No equation given. • We have assumed it to be equal to = Output from Industries at current prices – (Government Final Expenditure consumption and + Individual Consumption Expenditure)	• Under Direct control of the countries. • Impacts ○ How industries change policies and practices ○ How Government policies to incentive are able to impact industries. ○ Government's expenditure through public policies on health and education etc. which have an indirect impact on the Human and Natural capital.
3	Rental rate for Agricultural Land	R_{ik}	$RPA_{ij} = \frac{1}{A} \sum_{k=1}^{159} R_{ik}\ P_{ijk}\ Q_{ijk}$	• Based on the GTAP Database. • Unable to ascertain the equation and process for calculating Rental Rate.	• Under Indirect control • Affects how Rental Price per Hectare of Crops is calculated which has a bearing on the Agricultural Land as part of the Natural Capital. • It affects: ○ How countries invest in different crops and the cropland area

4	Rental rate for Fossil Fuels	$Rental\ Rate_i$	$Wealth\ of\ resource_t\ 'i' = Stock_{ti}.\overline{Price_{ti}}\ .Rental\ Rate_i$	• Based on the GTAP Database. • Unable to ascertain the equation and process for calculating Rental Rate.	• Affects the overall Wealth of Resource of Fossil Fuels
5	Rental rate for Minerals and Metals	$Rental\ Rate_i$	$Wealth\ of\ resource_t\ 'i' = Stock_{ti}.\overline{Price_{ti}}\ .Rental\ Rate_i$	• Based on the GTAP Database. • Unable to ascertain the equation and process for calculating Rental Rate.	• Affects the overall Wealth of Resource of Minerals and Metals

6	Stock commercially available	*Stock commercially available*$_t$	$Wealth\ of\ Timber_t = Stock\ commercially\ available_t.\overline{Price}\ .Rental\ Rate$	• Variables that go into the calculation of this are – Forest Area, Percentage of Volume commercially available and Timber Density.	• Under Indirect control of the countries.
					• This affects how players engage with each other through Trade agreements and the production of different kinds of wood.
					• How Forest area can be affected via changes in:
					  ○ Agricultural policies – shift to agriculture
					  ○ Forest policies to increase the area or shift to other kinds of wood,

					○ Forest fires to decrease the area.
7	Stumpage Price	$\overline{Price}$	$Wealth\ of\ Timber_t = Stock\ commercially\ available_t . \overline{Price}\ . Rental\ Rate$	• As per the report it is dependent on Wood production and Value of wood production.	• Under Indirect control of the countries. • Affects Trade agreements on timber and the production and export of other different kinds of wood. • The stumpage price can further affect how much forest area is developed; thereby affecting other non-timber benefits accrued.
8	Value of non-timber forest benefits (NTFB)	P_t	$ESW_t = \int_t^T P_t\,.(Q_t.r_t)\,.e^{-\delta.t}.dt$	• Marginal contribution of the Ecosystem Service flows to inter-temporal economic welfare. • This needs to be derived as per the Ecosystem Service Valuation Database (ESVD) by De Groot (2010).	• Affects human and produced capital as well. • Under the indirect control of the countries.
9	Carbon Damages	-	-	• Based on method developed by Arrow et al (2012).	• Crucial for calculating the global carbon emissions and global carbon damages and assigning carbon damages to countries.

					• This is a main part of how the players (countries) interact with each other.
10	Oil Capital Gains	-	-	• Depends on the increments in rental price of oil and stocks of oil available. • Gains in oil prices are allocated to those countries that consume oil.	• Affects how countries that depend on oil imports may be negatively impacted as their capacity to build other capital forms is impacted by higher prices.

Table 2: Classification of variables

Sl. No.	Variables	Symbol	Kind of Relationship (Direct/ Inverse)	Ratio of Change/ 'k' factor required	Temporality (Immediate/ Long-term)	Player control (Direct and Indirect)	How to Change this Variable
Human Capital							
1	Human Capital	H	• Direct relationship with Educational Attainment, discount rate, and Population above the age of 5.	• Exponential of Educational attainment and discount rate– changes in these 2 variables can result in major impact.	• Immediate impact	• Indirect	• Through Education policies, that makes education free and compulsory and the number of years for which it is so. • Through population policies such increase child mortality and health till age of 5.
2	Shadow Price of Human Capital	$SP_{HC\ (t)}$	• Direct relationship with Compensation of Employees and Average life's working period and	• Exponential of Market rate of interest.	• Long term impact	• Indirect	• Wage rate – through government policies, industry practices as mentioned below. • Labor policies • Health policies (via mortality rates)

Sl. No.	Variables	Symbol	Kind of Relationship (Direct/ Inverse)	Ratio of Change/ 'k' factor required	Temporality (Immediate/ Long-term)	Player control (Direct and Indirect)	How to Change this Variable
			market rate of interest.				
3	Average life's Working period	T	• It is assumed to have a direct relationship with the Mortality Rates and Labor force.	• Changes in the labor force can have a major impact on T. • Changes in the Mortality Rates will not affect the average working life period majorly.	• Mortality rates may have an impact over the long term. • Employmen t practices can have impact in the short-term.	• Indirect	• Health Policies – health care services, Health Insurance, Hospitals incentivisation • Employment practices of Industry Players/ Industry lobbies • Labor policies implemented by the Government
4	Compensati on of Employees	$\bar{r}$	• Direct relationship with both Wage Rate and Labor Force Participation rate.	• Change in the Wage rate is sufficient to create a large enough impact in the Compensation of employees. • Labor Force	• Immediate impact for Wage rate. • Long-term impact for Labor force participatio n rate.	• Indirect	• Employment practices of Industry Players/ Industry lobbies • Labor policies implemented by the Government

Sl. No.	Variables	Symbol	Kind of Relationship (Direct/ Inverse)	Ratio of Change/ ‘k’ factor required	Temporality (Immediate/ Long-term)	Player control (Direct and Indirect)	How to Change this Variable
Produced Capital							
5	Investment	I	• Direct relationship with →Output from Industries at current prices →Government Final Expenditure consumption and →Individual Consumption Expenditure)	• Any change in Output from Industries and Government Final Expenditure will result in a major change in ‘I’. • Changes in Individual consumption expenditure might not create a big enough impact	• Long-term impact	• Direct	• Changes in investment made in any Industry • Government Budgets/ Expenditure policies • Tax holidays
Natural Capital: Agricultural Land							
6	Rental Price per hectare	RPA_{ij}	• Direct relationship with Quantity, Price and Rental Rate of crops.	• Changes in Price and Quantity of crops produced will result in bigger impact.	• Immediate impact	• Indirect	• Quantity - through Agricultural policies and Budgets. • Price - through subsidies and Minimum

Sl. No.	Variables	Symbol	Kind of Relationship (Direct/ Inverse)	Ratio of Change/ 'k' factor required	Temporality (Immediate/ Long-term)	Player control (Direct and Indirect)	How to Change this Variable

			• Inverse relationship with the area harvested in crops. More the area harvested, lesser the rental price.	• Calculation of the Rental rate is not known. But it is assumed that changes in Rental rate – might not result in big changes.
				• Change in the area harvested will have a major impact on RPA_{ij}.
							price support schemes of the government.
							• Trade agreements with Industry players on agricultural crops, and machinery etc.
							• Area harvested through -
							  ○ Forest policies,
							  ○ Land acquisition policies
							  ○ Pest Control

7	Total Wealth per hectare	Wha_{ij}	• Direct relationship with Rental Price per hectare. • Inverse relationship with the Discount rate, r and time.	• Any change in the Rental Price per hectare will result in a bigger change in the Wealth per hectare.		• Indirect	• Through the variables in the calculation of Rental Price per hectare as mentioned above.

Sl. No.	Variables	Symbol	Kind of Relationship (Direct/ Inverse)	Ratio of Change/ 'k' factor required	Temporality (Immediate/ Long-term)	Player control (Direct and Indirect)	How to Change this Variable
Natural Capital: Forest Resources							
8	Stock Commercially Available	$Stock\ commercially\ available$	• According to the method mentioned in the IWI Report, it is dependent on Forest Area, Timber Density, Percentage of total volume commercially available. • Assumed that it has a direct relationship with all these variables.		• Long term impact	• Indirect	• Volume commercially available – through Trade agreements • Forest area through – ○ Agricultural policies – shift to agriculture, ○ Forest policies to increase the area or shift to other kinds of wood, ○ Forest fires to decrease the area.
9	Stumpage Price	$\overline{Price}$	• But it is dependent on Wood production and		• Long term impact	• Indirect	• Wood production and Value of Wood production can be changed through trade

Sl. No.	Variables	Symbol	Kind of Relationship (Direct/ Inverse)	Ratio of Change/ 'k' factor required	Temporality (Immediate/ Long-term)	Player control (Direct and Indirect)	How to Change this Variable
			value of wood production.				agreements on Export and Prices. • Agricultural policies, Forest policies to increase or decrease forest area and grow different kinds of wood.
10	Ecosystem Services Wealth	ESW_t	• Direct relationship with Percentage of forest area used for the extraction of NTFB, Value of non-timber forest benefits and Forest Area.	• Equation missing for the calculation of NTFB. • Exponential relationship with the discount rate. • Any change in Forest area, will have a big enough impact.	• Long term impact	• Indirect	• Forest area through – ○ Agricultural policies – shift to agriculture, ○ Forest policies to increase the area or shift to other kinds of wood, ○ Forest fires to decrease the area.
Natural Capital: Fossil Fuels							

Sl. No.	Variables	Symbol	Kind of Relationship (Direct/ Inverse)	Ratio of Change/ 'k' factor required	Temporality (Immediate/ Long-term)	Player control (Direct and Indirect)	How to Change this Variable
11	Wealth of resource	$Wealth\ of\ resource_t\ 'i'$	• Direct relationship with Stock, Prices and Rental Rate.	• Change in any of the variables, can create a big enough change in the overall wealth of resource.	• Long-term impact	• Indirect	• Through changes in Production, Rental Rate and Prices as mentioned below.
12	Reserves	$Stock_{ti}$	• Direct relationship with the Production of Fossil Fuels. • Based on Stock of a constant year.	• Change in Production value leads to change in Stock value of that particular year.	• Long-term impact	• Indirect	• Through changes in the production of fossil fuels (Oil, Natural Gas, Coal). • Industry/ Manufacturing/ Transport/ Automobile Lobbies can influence production. • Government can influence production through changing prices e.g. Diesel or Petrol rates.
13	Price	$\overline{Price_{ti}}$	• Prices based on different price		• Immediate impact	• Indirect	• Price can be changed through

Sl. No.	Variables	Symbol	Kind of Relationship (Direct/ Inverse)	Ratio of Change/ 'k' factor required	Temporality (Immediate/ Long-term)	Player control (Direct and Indirect)	How to Change this Variable
			indices for each fossil fuel. These need to be adjusted for inflation before averaging over time using the GDP Inflator				○ Trade agreements ○ Demand by various industries – automobiles, manufacturing etc.
14	Rental Rate	$Rental\ Rate_i$	• Based on the GTAP database. But unable to ascertain the calculation method/ equation.		• Long-term impact	• Indirect	
Natural Capital: Minerals and Metals							
15	Wealth of resource	$Wealth\ of\ resource_t\ 'i'$	• Direct relationship with Stock, Prices and Rental Rate.	• Change in any of the variables, can create a big enough change in	• Long-term impact	• Indirect	• Through changes in Production, Rental Rate and Prices as mentioned below.

Sl. No.	Variables	Symbol	Kind of Relationship (Direct/ Inverse)	Ratio of Change/ 'k' factor required	Temporality (Immediate/ Long-term)	Player control (Direct and Indirect)	How to Change this Variable
				the overall wealth of resource.			
16	Reserves	$Stock_{ti}$	• Direct relationship with the Production of each Mineral and Metal • Based on Stock of a constant year.	• Change in Production value leads to change in Stock value of that particular year.	• Long-term impact	• Indirect	• Through changes in the production of each of the 10 identified minerals and metal. • Investment by Industry/ Manufacturing lobbies. • Government can incentivize production of these metals through changing prices.
17	Price	$\overline{Price_{ti}}$	• Prices based on the World annual market prices, which are to be converted to 2005 constant prices and average prices	• Exact equation for doing so is not mentioned.	• Immediate impact	• Indirect	• Price can be changed through ○ Trade agreements ○ Demand by various industries – construction, manufacturing etc.

Sl. No.	Variables	Symbol	Kind of Relationship (Direct/ Inverse)	Ratio of Change/ 'k' factor required	Temporality (Immediate/ Long-term)	Player control (Direct and Indirect)	How to Change this Variable
			for each mineral computed.				
18	Rental Rate	$Rental\ Rate_i$	• Based on the GTAP database. But unable to ascertain the calculation method/ equation.		• Long-term impact	• Indirect	