# Changing Wealth of Nations 2021: Methods and Data

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# I. Introduction

This document describes the estimation of comprehensive wealth by the World Bank. Building on the foundation laid in previous work by the World Bank, including the *Expanding the Measure of Wealth* (1997), *Where is the Wealth of Nations?* (2005), *The Changing Wealth of Nations* (2011), and *The Changing Wealth of Nations (2018)*. The data and methods described in this document represent the latest stage in as part of *The Changing Wealth of Nations 2021*. *The Changing Wealth of Nations 2021* covers a much longer period (1995–2018) with improved data and country coverage than previous reports.

A nation's wealth consists of a diverse portfolio of assets, which together form the productive base of the national economy. These assets include:

- ***Natural capital***, comprising renewable natural capital which includes agricultural land (cropland and pastureland), protected areas, forests (timber and ecosystem services), mangroves and fisheries; and nonrenewable natural capital which includes fossil fuels and minerals;
- ***Produced capital***, comprising machinery, structures, equipment, and urban land;
- ***Human capital***, including the knowledge, skills, and experience embodied in the workforce;
- ***Net foreign assets***, including portfolio equity, debt securities, foreign direct investment, and other financial capital held in other countries.

A few methodological concepts and assumptions should be highlighted up front, as they are applied broadly to renewable and nonrenewable natural capital. The general concept of asset valuation is that the value should equal the discounted sum of net benefits an asset is expected to generate over its lifetime. For natural capital, the net benefits are the resource rents: the total value of production (or revenues) minus the total cost of production. In calculating the net present value for renewable and nonrenewable natural capital, a discount rate of 4 percent is used across all resources and years (as in the previous wealth reports). The lifetime of the resource for renewable natural capital is capped to 100 years, following the practice of the UK Office for National Statistics, while the lifetime for nonrenewable natural capital is estimated directly based on reserves and extraction paths.

The following sections dive into the methodological details for estimating each category of asset. The first sections deal with the components of natural capital. Section II focuses on non-renewable natural resources, including fossil energy, metals, and minerals. The discussion then turns to renewable resources. Section III looks at forests, including timber resources as well as ecosystem services provided by forests; section IV presents the data and methods for valuing agricultural land, including cropland and pasture; section V is dedicated to protected areas; and sections VI and VII to the new blue natural capital accounts for mangroves and fisheries. Following the discussion of natural capital, section VIII explains produced capital, section IX looks at net foreign assets, and section X discusses human capital. Finally, section XI describes the approach in estimating total wealth.

Data are reported in constant 2018 U.S. dollars, at market exchange rates. A country-specific gross domestic product (GDP) deflator (base year 2018) is used to bring all figures to real terms.

# II. Energy and Mineral Resources

Non-renewables resources valued in the World Bank wealth accounts include fossil energy and mineral resources. As described in *The Changing Wealth of Nations* (World Bank 2021), the value of a nation's stock of a non-renewable resource is measured as the present value of the stream of expected rents that may be extracted from the resource until it is exhausted. This value, $V_t$, is given as:

(2.1)
$$V_t = \sum_{i=t}^{t+T-1} \frac{\overline{R_t}}{(1+r)^{i-t}}$$

where $\overline{R_t}$ is a lagged, five-year moving average of rents in years $t$ (the current year) to $t$ – 4; $r$ is the discount rate (assumed to be a constant 4 percent), and $T$ is the lifetime of the resource. Rents in the current year are calculated as:

(2.2)
$$R_t = \pi_t q_t$$

where $\pi_t$ denotes unit rents, equal to revenues less production costs including a 'normal' rate of return on fixed capital and the consumption of fixed capital; and $q_t$ denoting the quantity of resource extracted. Rents are converted into constant US dollars at market rates using country-specific GDP deflators before averaging to obtain $\overline{R_t}$. The present value of rents from energy and mineral resources is estimated under the restrictive assumption that rents remain constant in future years. In applications of this methodology where more country-specific data might be available, the extraction path and expected future unit rents (based on projections of resource prices and extraction costs) may be modified.

The fossil energy resources valued in the World Bank wealth accounts are petroleum, natural gas, and coal. Metals and minerals valued in the wealth accounts include bauxite, copper, gold, iron ore, lead, nickel, phosphate rock, silver, tin, and zinc.

## A. Petroleum and natural gas

As noted, the value of a nation's stock of petroleum and natural gas is calculated as the present value of expected rents that could be obtained over the lifetime of the resource. Calculating the present value of future rents requires data for annual production, prices, production costs, and reserves. From existing reserves and current rates of production, the time to exhaustion of the resource is assumed. Data sources and methods for estimating each of these elements are described below.

### 1. Oil and natural gas production

Table 1 indicates the data sources for the production of petroleum and natural gas.

*Table 1: Data sources for production of petroleum and natural gas*

| Element | Data sources |
|---|---|
| **Production of Oil and Natural Gas** | • Rystad Energy, UCUBE (Upstream Database)<br>• International Energy Agency (IEA), "World Energy Statistics", IEA World Energy Statistics and Balances database (link)<br>• IEA, "World Conversion Factors", IEA World Energy Statistics and Balances database (link)<br>• BP, Statistical Review of World Energy (link)<br>• US Energy Information Administration, International Energy Statistics (link)<br>• UN Statistics Division, UN Monthly Bulletin of Statistics (link) |

The Rystad Energy UCUBE and IEA World Energy Statistics databases are subscription-based services. The BP, US EIA, and UN databases are free and publicly available. Slight differences exist between the data sources as to the scope of petroleum production. The IEA, BP, and US EIA data include crude oil, shale oil, oil sands, and lease condensates[1]. Rystad Energy and the UN MBS exclude lease condensates.

Production data from Rystad Energy, BP, UN MBS, and US EIA are in units of thousands of barrels of oil produced daily. Data from the IEA are converted into units of barrels from tons using country-specific estimates from the IEA of the average volume to mass ratio for crude oil supply. Where country-specific data are unavailable, an average conversion factor of 7.33 barrels per metric ton is assumed.

For natural gas, production is limited to the marketable production of dry natural gas. Data on production from the different sources are converted into common units of terajoules (TJ, or $10^{12}$ joules), assuming about 5,712 TJ per million barrels of oil-equivalent (Mboe), and about 1,067 TJ per billion cubic feet (bcf) of natural gas.

Data on petroleum and natural gas production are limited to production within national boundaries, including offshore marine boundaries; however, Rystad Energy also provides data for several joint

[1] Lease condensates are additional liquids that are recovered and separated by field facilities at oil and natural gas wells. They may contain pentane and a variety of hydrocarbons, depending on their density. Denser condensates may be darker in color and appear similar to light crude oil. Lighter condensates contain more natural gas liquids, such as ethane, propane, and butane and may be more translucent in color. Lease condensates (crude oil with an API gravity of 45° or higher) accounted for roughly about 23 percent of oil production between January 2015 and April 2021 in the continental United States. US EIA, "Crude Oil and Lease Condensate Production by API Gravity", https://www.eia.gov/petroleum/data.cfm#crude (accessed September 20th, 2021).

development zones, which are allocated to countries on the basis of revenue-sharing formulas. Joint zones include:

- Timor Sea JPDA (Joint Petroleum Development Area): The JPDA was created by the Timor Sea Treaty between Timor-Leste and Australia in 2002. By treaty, Timor-Leste receives 90 percent of revenues derived from JPDA; Australia receives 10 percent. Production, revenue, and resource values from the JPDA are allocated thusly. Malaysia/Thailand Joint Development Area: The JDA was created by a memorandum of understanding between Malaysia and Thailand in 1979, which, as an interim measure, provided that the two countries would share equally in the proceeds of the area's resources. Both Thailand and Malaysia continue to make legal claims to the shared area. Part of the JDA is also claimed by Vietnam (the "Tripartite Overlapping Claim Area," or TOCA). No formal agreement has been publicized for revenue-sharing from the TOCA. Production, revenue, and resource values from the Malaysia-Thailand JDA are allocated 50/50.Saudi-Kuwaiti Neutral Zone: Oil in this border area between Saudi Arabia and Kuwait is explored under a joint operating agreement that gives the two countries equal shares in production. Data on production, revenue, and resources from Rystad are allocated thusly.

- Nigeria-Sao Tome & Principe Joint Development Zone: The JDZ is an area of overlapping maritime boundary claims, defined by treaty in 2001. The treaty established a 60/40 resource sharing formula between Nigeria and Sao Tome and Principe, respectively. Production, revenue, and resource values from Rystad are allocated thusly.

Production data from the different sources are combined by applying the following decision rules:

- The data source that provides the best coverage over time, beginning in 1980, is given priority;

- If multiple sources provide equal temporal coverage, then for countries where data are available from at least three different sources for any year after 1980, the series that is generally closest to the median estimate of production for that country is taken;

- If two sources of data provide equal temporal coverage—and only two sources of data are available for that country—sources are assigned priority according to the following order: Rystad Energy, IEA, BP, UN MBS, and US EIA. The data from Rystad Energy are given highest priority because data on unit costs and revenues are also take from this source;

  Data from other sources may be used to fill gaps in the base series so long as data from those sources are basically consistent with the base series. "Basically consistent" is interpreted generously to mean that the difference in estimates between the two sources never exceeds ± 50 percent.

### 2. Oil and natural gas unit costs, prices, and unit rents

Unit rents are estimated using country-level averages of unit prices and production costs from the Rystad Energy UCUBE database. Using the terminology of Rystad Energy, unit prices are equal to unit revenues, which in the Rystad Enegy database are the sum of exploration expenditure, capital expenditures, exploration expenditure, operational expenditure, government take, and free cash flow in current US dollars per barrel (or barrel of oil equivalent for natural gas). Unit costs equal the sum of capital expenditures, operational expenditure, and exploration expenditure. Table 2 defines each of these price and cost components.

*Table 2: Components of unit rents for oil and natural gas, as calculated using Rystad Energy data*

| **Calculation of unit revenues, unit rents, and rental rates for oil and natural gas**<br><br>**Unit revenue = exploration expenditure + capital expenditure (capex) + operating expenditure (opex) + government take + free cash flow**<br><br>**Unit cost = exploration expenditure + capex + opex**<br><br>**Unit rent = unit revenue – unit cost**<br><br>**Rental rate = unit rent / unit revenue** | |
|---|---|
| **Unit revenue component** | **Definition** |
| ***Exploration expenditure*** | Costs associated with acquiring acreage, doing seismics, and drilling wildcats or appraisal wells to discover and delineate oil and gas fields |
| ***Capex*** | All development costs related to facilities and drilling of wells. The initial capital expenses are related to establishing the facility and necessary infrastructure, as well as pre-drilling costs, often termed development capex. Throughout the field life capital expenses include drilling of more development wells (well capex) and modifications done to the facility, processing system or e.g. subsea infrastructure. |
| ***Opex*** | Costs necessary to maintain the operations of a well or asset, including transportation costs for delivering oil and gas from the production point to the point of pricing; SG&A costs, which cover administrative staff costs, office leases, stocks and stock option plans, and professional expenses (legal, consulting, insurance); and lease, fixed, and variable production costs |
| ***Government take*** | Royalties (the sum of gross taxes); government profit oil (oil paid in kind to the government); income tax (all profit-based taxes, including corporate taxes); and other taxes (e.g., withholding and windfall taxes) |

| | |
|---|---|
| ***Free cash flow*** | Cash flow available to investors and creditors, a residual equal to subtracting exploration expenditure, capex, opex, and government take from total revenue |

*Source: Excerpted from Rystad Energy (2015), with paraphrasing and editing by authors*

The country data from Rystad Energy on unit revenues and costs for oil and natural gas are used to calculate average rental rates by region[2]. Regional rental rates are used due to data limitations for some countries, particularly in Sub-Saharan Africa, for which Rystad may only have field-level data for a small number of recently developed assets. The regional averages are weighted by production, with negative unit rents set to zero before averaging[3]. There is one exception. Due to volatility and large negative rents in data for the Sub-Saharan Africa, a simple average of the rental rates for all other regions (excluding North America) is applied. Regional rental rates for oil and natural gas are illustrated in figures 1 and 2 below.

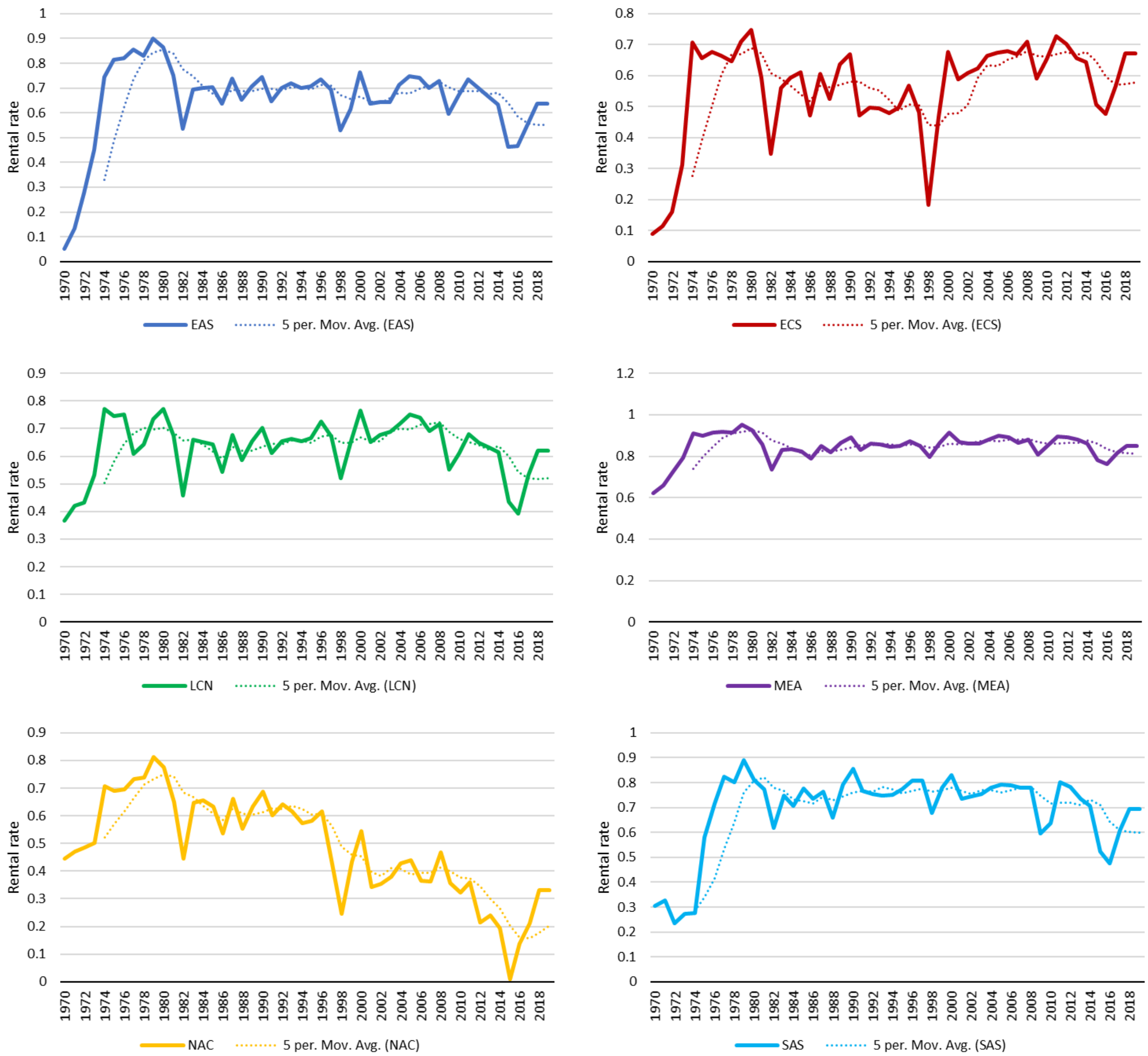
Rents are converted to constant year 2010 US dollars at market exchange rates. In accordance with common practice by national statistical offices, a lagged, five-year average of unit rent is taken to mitigate the effects of year-on-year price volatility[4].

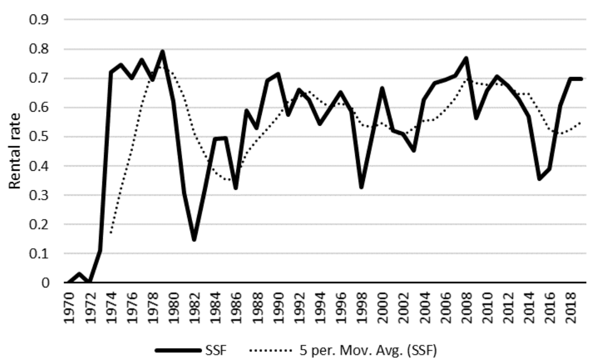
[2] The World Bank regions are: East Asia and Pacific, Europe and Central Asia, Latin America and Caribbean, Middle East and North Africa, North America, South Asia, and Sub-Saharan Africa. Countries of all income levels are included in these geographic regions. See for a complete listing of countries by region.

[3] Unit rents may be negative particularly in the early stages of developing an oil or gas field, when significant capital expenditures must be made to bring the field into production. Rents may also be negative for more mature assets where producers receive additional subsidies or other forms of support to make production economical.

[4] This smoothing practice is used in countries that compile asset accounts for subsoil assets such as the United Kingdom, Australia, Canada, and the Netherlands.

*Figure 1: Regional rental rates for oil*

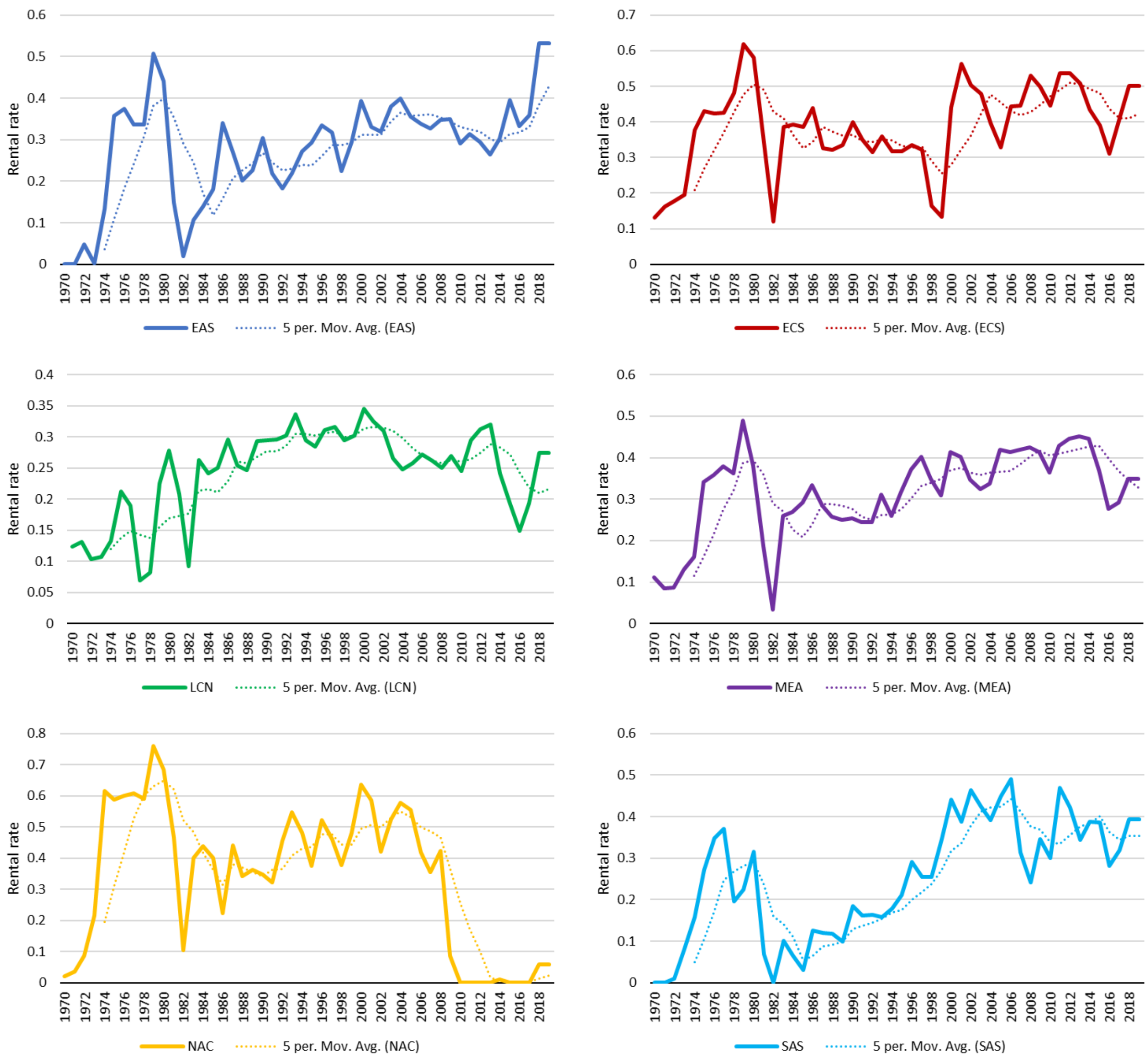


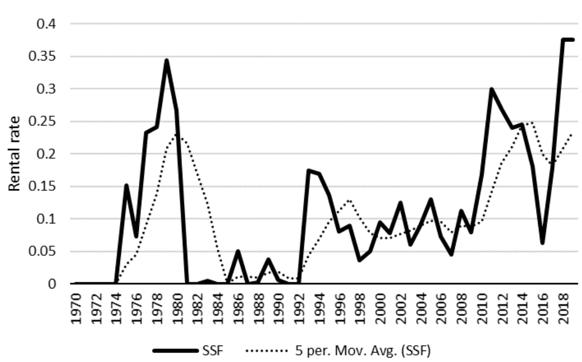




Notes: EAS = East Asia and Pacific; ECS = Europe and Central Asia; LCN = Latin America and Caribbean; MEA = Middle East and North Africa; NAC = North America; SAS = South Asia; SSF = Sub-Saharan Africa; all income levels included

*Source: World Bank estimates using Rystad Energy UCUBE database*

Figure 2: Regional rental rates for natural gas




Notes: EAS = East Asia and Pacific; ECS = Europe and Central Asia; LCN = Latin America and Caribbean; MEA = Middle East and North Africa; NAC = North America; SAS = South Asia; SSF = Sub-Saharan Africa; all income levels included; SSF rental rates represent simple world average (excluding NAC)

*Source: World Bank estimates using Rystad Energy UCUBE database*

### 3. Oil and natural gas reserves and time to depletion

Time to depletion of oil and natural gas is equivalent to the ratio of proved reserves to production. Proved reserves are those quantities of oil and natural gas that geological and engineering information indicates with reasonable certainty can be recovered profitably in the future from known reservoirs under existing economic and operating conditions. Data on proved reserves are available from BP and the US Energy Information Administration (Table 3).

*Table 3: Data sources for proved reserves of petroleum and natural gas*

| Component | Data sources |
|---|---|
| **Proved reserves of petroleum and natural gas** | • BP, Statistical Review of World Energy (link)<br>• US Energy Information Administration, International Energy Statistics (link) |

The BP data on oil and gas reserves are drawn from a variety of official statistics and data provided by the OPEC Secretariat, Cedigaz, World Oil and the Oil & Gas Journal and an independent estimate of Russian oil reserves based on information in the public domain. The US EIA data on oil and gas reserves for the United States are drawn from agency estimates; US EIA data for other countries is drawn primarily from the *Oil & Gas Journal*, and the estimates for Kuwait and Saudi Arabia each include one-half of the reserves for the Neutral Zone. Oil reserves include field condensate and natural gas liquids (NGLs) as well as crude oil. They also include an estimate of Canadian oil sands 'under active development' as a proxy for proved reserves.

For the sake of consistency, where BP data are used for production, BP data are also used for reserves; where US EIA data on production are used, the US EIA data on reserves are used. If data from the same source are not available for both reserves and production, then the BP data on reserves are given priority. If data on reserves are missing for a particular country, then an estimate of the average reserves-production (R-P) ratio for that region is applied using the BP data. For years prior to 1980, reserves are back casted by regressing a time trend from the existing years of data.

Unlike with previous versions of the World Bank wealth accounts, no cap is applied to the R-P ratio.

## B. Coal

As with oil and natural gas, calculating the value of a nation's coal resources requires data on production, prices, costs, and reserves. Each of these elements is described below.

## 1. Coal production

As with oil and natural gas, data on coal production are obtained from a variety of sources (Table 4).

*Table 4: Data sources for the production of coal*

| Element | Data sources |
|---|---|
| **Production of coal** | • International Energy Agency, World Energy Statistics (link)<br>• US Energy Information Administration, International Energy Statistics (link)<br>• UN Statistics Division, UN Monthly Bulletin of Statistics (link) |
| **Average net calorific value of coal production** | • International Energy Agency, World Energy Statistics (link) |

Among the different sources of data for coal production, the primary source is the IEA's World Energy Statistics database, which provides the most detailed estimates of production by specific grade of coal.

Coal production is standardized based on heat content and is broken down into two general categories: ***hard coal*** and ***brown coal***. Hard coal is defined by the International Coal Classification of the Economic Commission of Europe as coal with a gross calorific value that is greater than 5,700 kcal/kg. Brown coal is all coal with a gross calorific value less 5,700 kcal/kg (UN 1988). For countries with more detailed data from the IEA, hard coal production is further disaggregated into ***bituminous steam coal (including anthracite)*** and ***coking coal***. Steam coal is coal that is used primarily for generating electricity. The coal is fired in a boiler to heat water, producing steam that drives a turbine. Coking coal, or metallurgical coal, is hard coal with a low volatile matter content that is primarily used to make blast-furnace coke and foundry coke in the manufacture of steel. High-grade coking coal is produced by relatively few countries (just 5 countries accounted for about 80 percent of global production in 2020, China, India, Indonesia, Australia, and the United States). Thus, for countries with only data on total hard coal production, it is conservatively assumed that these countries only produce bituminous steam steal and not metallurgical coal. The IEA data cover more than two-thirds of all countries for coal production data are available from any source. The US EIA also provides disaggregated data on production of anthracite, bituminous, subbituminous, lignite, and metallurgical coal, but only for the most recent years. Subbituminous coal and lignite are taken as brown coal, and anthracite, bituminous, and metallurgical coal are taken as hard coal. For earlier years, data on coal production from the US EIA are reported only on a more aggregated basis for hard coal and brown coal. The more detailed breakdown in coal production by coal grade as a share of total coal production for the most recent years is assumed for these earlier years. The UN data are used only for gap-filling purposes because they report only aggregate hard and brown coal production.

In order to standardize coal production by heat content, IEA estimates of the average net calorific value (NCV) of coal production are used, as obtained from the World Energy Statistics database[5]. Where a country is missing IEA data on the average NCV of production for certain years, the earliest or latest value for that country is used to gap-fill missing observations. If a country is missing IEA data on average NCV of production for all years, then a regional average is applied for that specific rank of coal. Global averages may be applied for regions where no countries have IEA data on average NCV of production.

### 2. Coal unit prices, costs, and unit rents

Data sources for unit production costs and prices for coal are shown in Table 5.

*Table 5: Data sources for coal prices and production costs*

| Element | Data sources |
|---|---|
| **Unit production cost of coal** | • Wood Mackenzie, Global Economic Model (GEM) database (link)<br>• Case studies from various sources<br>• World Bank, Manufactures Unit Value (MUV) Index, Global Economic Monitor Commodities database (link) |
| **Unit price of coal** | • World Bank, Global Economic Monitor Commodities database (link)<br>• Government of Australia, Office of the Chief Economist, Department of Industry, Innovation and Science, "Resources and Energy Quarterly" (link)<br>• IEA, *Coal Information* (Paris, OECD: various years) |

The primary source of data for calculating unit production costs for coal is the Wood Mackenzie Global Economic Model (GEM) database. The GEM database is a subscription service that provides mine-level estimates of costs for around 1,300 mines in 14 countries: Australia, Botswana, Canada, Chile, China, Colombia, Indonesia, Mongolia, Mozambique, New Zealand, Russian Federation, South Africa, United States, Venezuela RB, and Vietnam. Together, these countries accounted for 85 percent of the world's hard coal production in 2014. The Wood Mackenzie data primarily cover the late 2000s and early 2010s, although data for Australian mines stretch back to 1993. Production costs are estimated separately for mines producing ***thermal coal*** and those producing ***metallurgical coal***. Production costs include operating cash costs plus capital expenses. Costs and prices for coal are normalized on the basis of energy content (USD per kcal), assuming the average NCV of production for thermal coal and metallurgical coal as reported by the IEA. Because the Wood Mackenzie data for thermal coal encompass bituminous steam

[5] Note that the net calorific value (NCV) is slightly lower than the gross calorific value (GCV) for coal. The NCV subtracts the energy required to vaporize the moisture content in coal from the GCV.

coal as well as brown coal, the production cost per unit of energy (kcal) is assumed to be the same for both bituminous steam coal and brown coal. Metallurgical coal mainly includes coking coal.

Because costs are reported at the mine level in the Wood Mackenzie GEM database, and some mines produce multiple grades of coal, only those mines that produce either thermal coal or coking coal—but not both—are included. Also, while Wood Mackenzie provide projections for production, costs, and prices for mines under development, for the calculation of rents, only mines that were producing coal in at least half of the years for which Wood Mackenzie has data for that country are included. Mines must currently be in production for the year in which they report cost data. These rules for inclusion in the sample used to calculate average production costs at the country level help ensure some consistency across time in the sample of mines per country and excludes assets still in the early start-up phase when large capital investments are needed to begin operations. Applying these rules restricts the total number of reporting assets to 300, including 227 mines for thermal coal and 73 mines for metallurgical coal. The number of assets per country for which production cost data are available from Wood Mackenzie is shown in Table 6. Costs are averaged at the country level by weighting costs for individual mines by total production.

*Table 6: Number of mines in the Wood Mackenzie GEM database used to calculate production costs for thermal coal and metallurgical coal by country*

| Country | Thermal | Metallurgical |
|---|---|---|
| **Australia** | 15 | 9 |
| **Botswana** | 1 | 0 |
| **Canada** | 7 | 9 |
| **Chile** | 1 | 0 |
| **China** | 34 | 6 |
| **Colombia** | 9 | 1 |
| **Indonesia** | 22 | 0 |
| **Mongolia** | 5 | 2 |
| **New Zealand** | 1 | 1 |
| **Russian Federation** | 27 | 9 |
| **United States** | 30 | 34 |
| **Venezuela, RB** | 1 | 0 |
| **Vietnam** | 25 | 1 |
| **South Africa** | 49 | 1 |
| **Total** | 227 | 73 |

*Note: Sample includes mines which are used to calculate production costs for at least one year per country*

Production costs for additional countries and years not covered by the Wood Mackenzie database are gathered from academic articles, case studies, official statistics, industry reports, and other sources. These additional sources are listed in Table 7 below. These additional data sources include old studies from the 1980s and 1990s that had been used previously to estimate coal production costs for the World Bank's adjusted net savings (ANS) indicator.

*Table 7: Additional sources of production cost estimates for coal*

| ***Thermal coal*** | | |
|---|---|---|
| **Country** | **Years** | **Source** |
| **Canada** | 1994 | IEA (1995a) |
| **China** | 1987 | Doyle (1987) |
| **Colombia** | 1994 | IEA (1995a) |
| **Czech Republic** | 1992-1994 | IEA (1995a) |
| **India** | 1988 | Bhattacharya (1995) |
| **India** | 2013 | Greenpeace (2014) |
| **Indonesia** | 1994 | IEA (1995a) |
| **Mexico** | 1989 | World Bank (1989) |
| **Poland** | 1991-1993 | IEA (1995b) |
| **Poland** | 2003 | Kudelko, Kaminski, and Pekala (2007) |
| **Poland** | 2014 | Bukowski et al (2014); Ernst & Young (2014); assumes brown coal is 43% of thermal coal production and bituminous steam coal is 57%, using European average cost for brown coal |
| **Russian Federation** | 1980, 1985, 1990 | Tretyakova and Heinemeier (1986) |
| **South Africa** | 1994 | IEA (1995a) |
| **United States** | 1994 | IEA (1995a) |
| ***Metallurgical coal*** | | |
| **Country** | **Years** | **Source** |
| **Canada** | 1994 | IEA (1995a) |
| **India** | 1988 | Bhattacharya (1995) |
| **Poland** | 1994 | IEA (1995b) |
| **Poland** | 2003 | Kudelko, Kaminski, and Pekala (2007) |
| **South Africa** | 1994 | IEA (1995a) |

Data on production costs from the Wood Mackenzie database and additional data sources do not cover all countries and years for which data on coal production are available, so additional gap-filling and extrapolating is needed to construct complete time series.

For thermal coal, unit costs for Australian (1993-2014) and Indonesian (2000-2014) mines from the Wood Mackenzie database are averaged and then used as a nominal index to extrapolate cost trends for other countries and years. This is because the Australia and Indonesia data provide the best coverage and are generally consistent with trends in reference prices for thermal and metallurgical coal. For metallurgical coal, trends in nominal unit costs for Australian coal (1993-2014) are taken as a reference index for other countries. Note that the export unit value of Australian coal is often used in the industry as a benchmark for prices, so this method for extrapolating trends in unit costs has some precedent. For years prior to 1993, where data on unit production costs are not available from Wood Mackenzie, costs are extrapolated using the World Bank's Manufactures Unit Value (MUV) index. The MUV index was also used in previous versions of the World Bank's ANS and wealth accounts databases to extrapolate unit production costs for coal; however, the MUV index does a poor job of tracking price and cost trends for coal in the mid-2000s and early 2010s, during which time prices and costs for coal spiked and dropped quite dramatically. This is why the Australia-Indonesia index using the Wood Mackenzie data is preferred for years after 1993.

For the nominal cost index, price levels in 2000 = 100. Costs in earlier or later years are extrapolated as:

(2.3)
$$C_i = C_n * E_i \;/\; E_n$$

where $C_i$ is the unit cost in the current year $i$ being gap-filled (nominal terms); $C_n$ is the cost in the base year $n$ for which data are available from Wood Mackenzie or other sources; $E_i$ is the index value in year $i$; and $E_n$ is the index value in the base year.

Internal gaps exist for countries with new data for the 2000s and 2010s from Wood Mackenzie and old data from the 1980s and early 1990s. While the new data provides a more accurate basis for estimating production costs in recent years, it is assumed that the old data provide a more reliable basis for estimating production costs for the earlier years than simply extrapolating from the new data using the nominal cost index described above. For countries with both old and new cost data, cost estimates that are extrapolated for earlier years using the nominal index are rescaled to align with the original case studies. This rescaling is done by the following method. First, the nominal cost index is transformed logarithmically such that:

(2.4)
$$C_{index} = \ln C_n + \ln E_i - \ln E_n$$

where $C_{index}$ is the ln of unit production costs in current year $i$, extrapolated according to the nominal cost index. For countries with both new and old data on production costs, the gap in the log-transformed unit production costs, ln($C_i$), is then interpolated linearly such that:

(2.5)
$$C_{linear} = \ln C_n - (y_n - y_i)\left(\frac{\ln C_n - \ln C_0}{y_n - y_0}\right)$$

where $C_{linear}$ is the ln of unit production costs in the current year $i$, interpolated linearly; $C_n$ is the unit production cost in year $n$, the earliest year of new data from the Wood Mackenzie database or other source; $C_0$ is the unit production cost in year 0, the latest year of old data from the case studies used previously for the World Bank's ANS indicator; $y_n$ is year $n$; $y_0$ is year 0; and $y_i$ is year $i$. Finally, $C_{index}$ and $C_{linear}$ are combined:

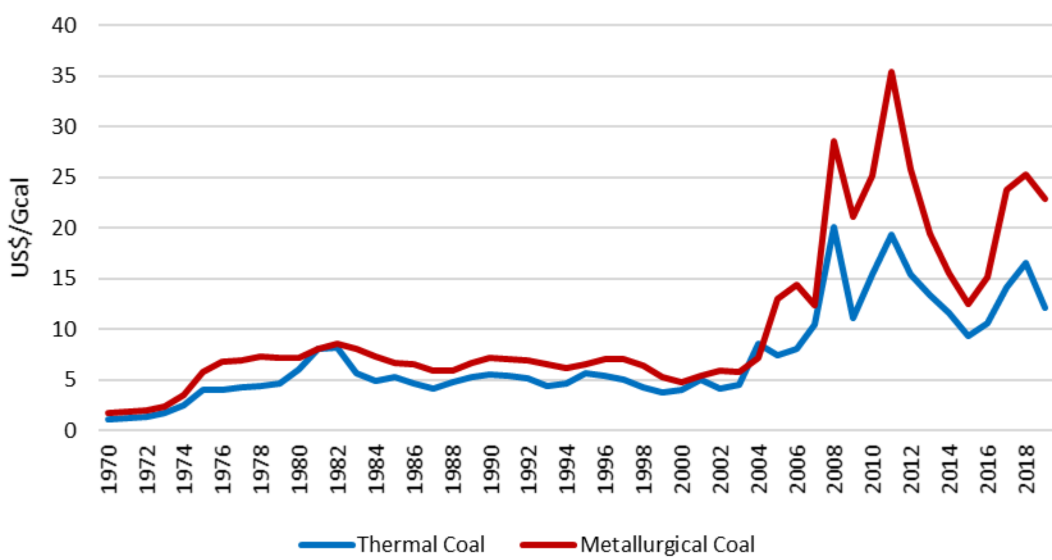
(2.6)
$$\ln C_i = C_{index} - (C_{index} - C_{linear})\left(1 - \frac{y_i - y_0}{y_n - y_0}\right)$$

so that $C_{index}$ and $C_{linear}$ are weighted depending on how close the current year ($y_i$) is to the year at the beginning of the gap ($y_0$). This method of combining the interpolated production costs ensures that the interpolated costs match up smoothly with the cost study estimates.

Estimates of unit prices for thermal coal are obtained from the World Bank's Global Economic Monitor Commodities database. Unit prices for thermal coal represent the average benchmark price for thermal coal exported from Australia, Colombia, and South Africa (FOB basis), standardized in terms of USD per kcal. This benchmark price is applied to all countries; differences in the quality of coal produced by individual countries are accounted for by standardizing prices according to energy content. The reference price per kcal is applied to both bituminous steam coal and brown coal.

Unit prices for metallurgical coal are pinned to the reference price for exports of Australian coking coal (FOB basis). Data on reference prices for Australian coking coal are obtained from various years of the IEA's *Coal Information* reports. Data for more recent years are obtained from quarterly reports by the Office of the Chief Economist, Department of Industry, Innovation and Science, Australian Government. Prices for metallurgical coal are standardized in terms of USD per kcal by assuming the average NCV for exports, using the conversion factors from the IEA World Energy Statistics database. Trends in the reference prices for metallurgical and thermal coal are illustrated in Figure 3 below.

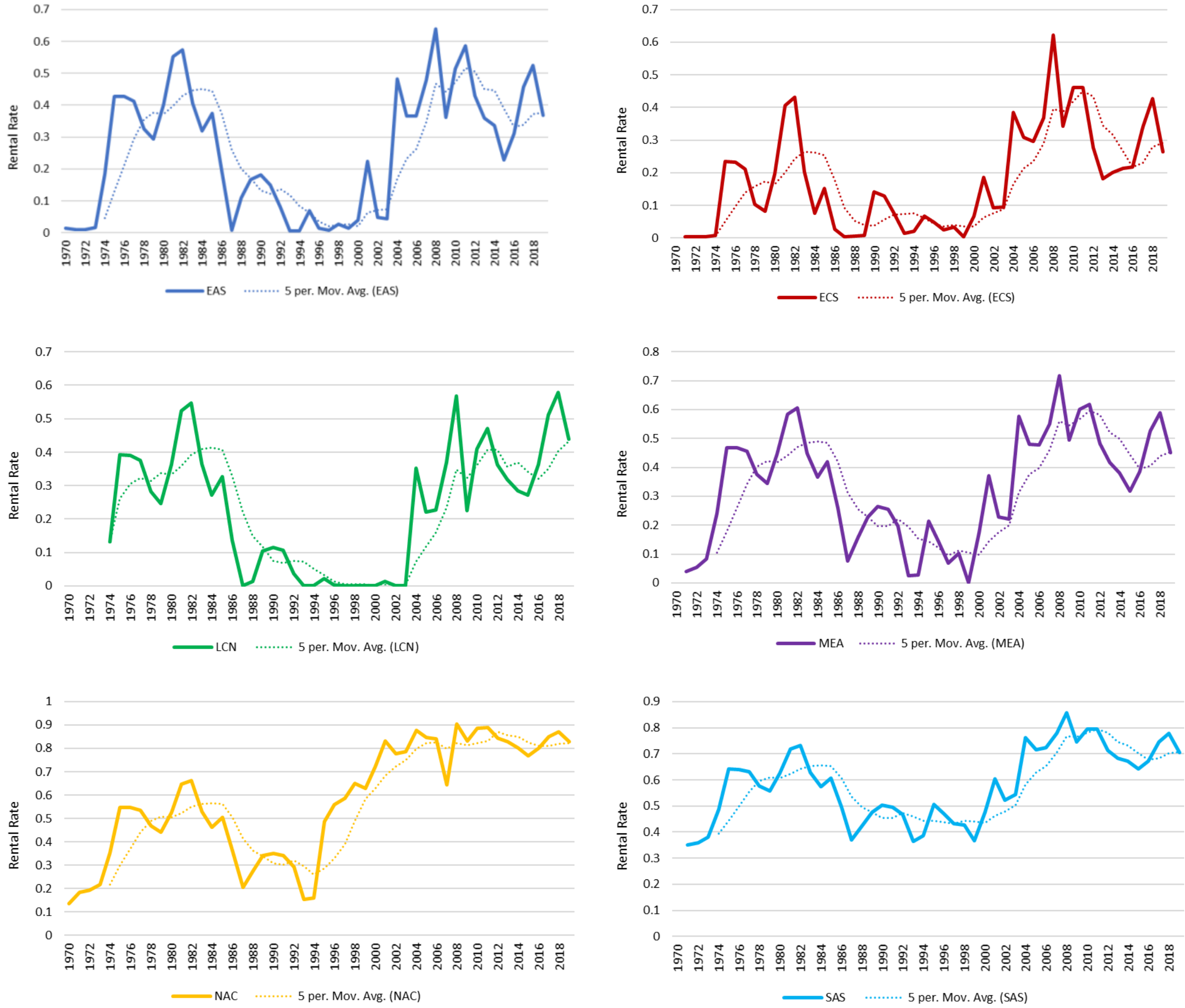
*Figure 3: Reference prices for thermal and metallurgical coal used in the estimation of coal rents*

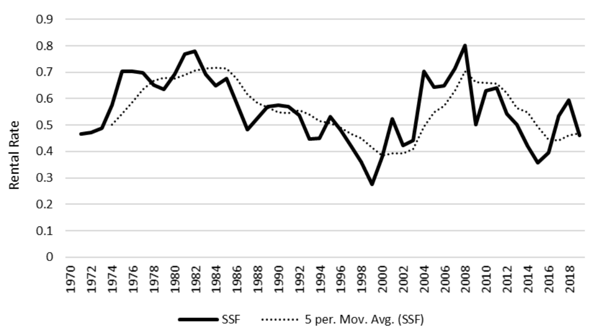



*Note: Costs are normalized on the basis of energy content; 1 Gcal = 1 billion calories = 1 million kilocalories (kcal)*

Country-level estimates of unit production costs and prices are then used to calculate average rental rates by region for thermal and metallurgical (coking) coal. Average rental rates are weighted by production. For regions lacking estimates of production costs (Middle East and North Africa), a simple world average of rental rates is applied. Where unit costs exceed prices, zero rents are assumed. The resulting rental rates for thermal and metallurgical coal by region are illustrated in Figure 4 and Figure 5.

*Figure 4: Average rental rates for thermal coal by region*

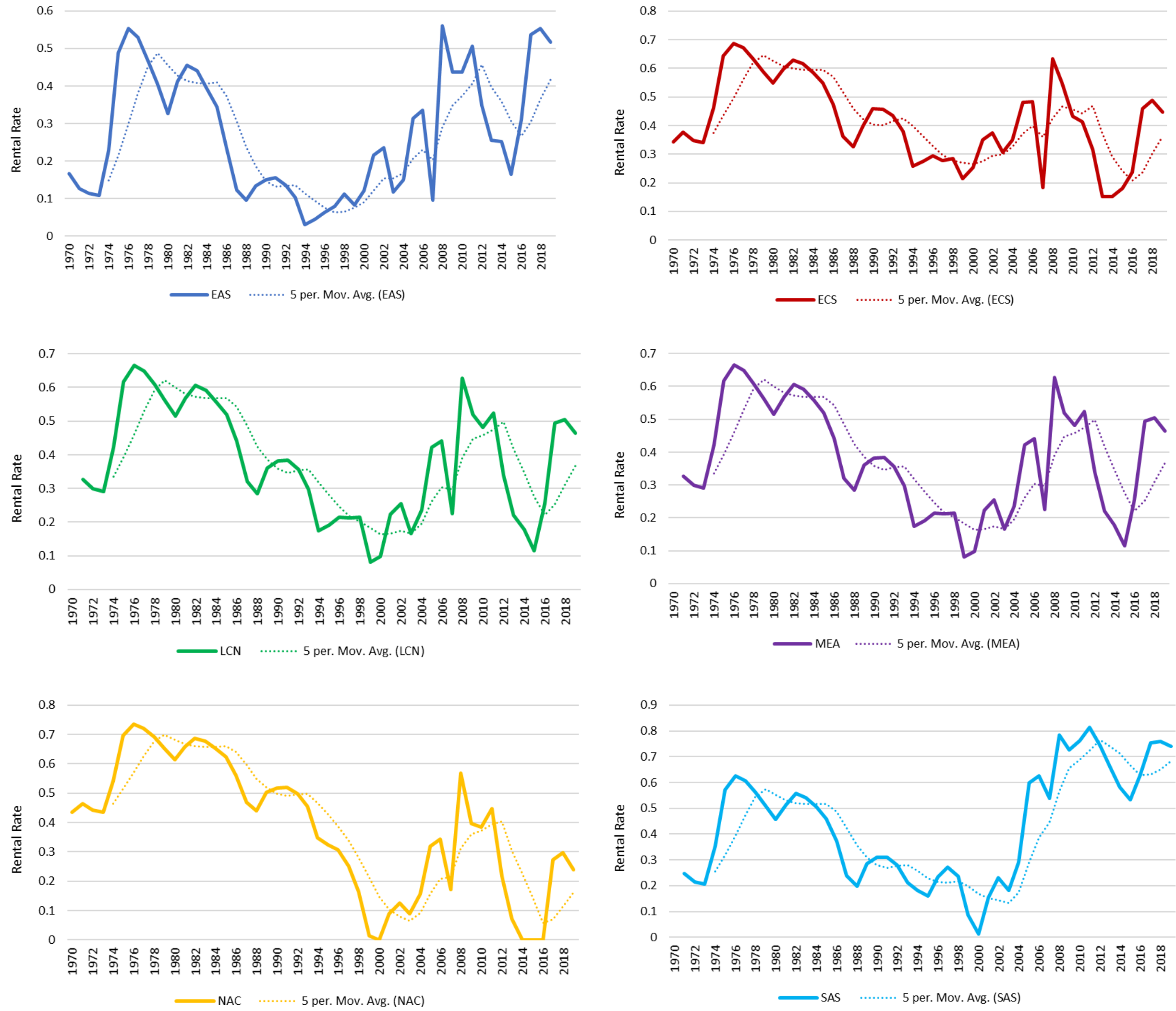


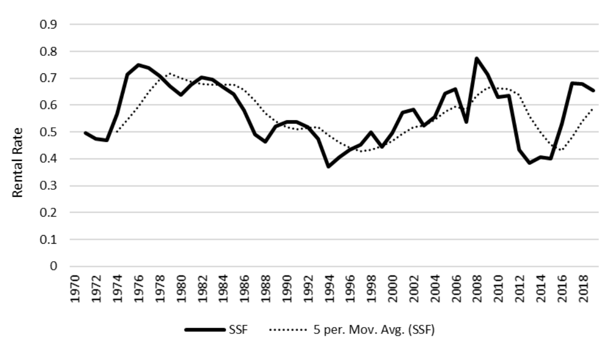




Notes: EAS = East Asia and Pacific; ECS = Europe and Central Asia; LCN = Latin America and Caribbean; MEA = Middle East and North Africa; NAC = North America; SAS = South Asia; SSF = Sub-Saharan Africa; all income levels included

*Source: World Bank estimates*

*Figure 5: Average rental rates for metallurgical coal by region*




Notes: EAS = East Asia and Pacific; ECS = Europe and Central Asia; LCN = Latin America and Caribbean; MEA = Middle East and North Africa; NAC = North America; SAS = South Asia; SSF = Sub-Saharan Africa; all income levels included

*Source: World Bank estimates*

## 3. Coal reserves and time to depletion

Data on proved reserves of coal are provided from the sources listed in Table 8 below. Time to depletion of coal reserves is calculated as the ratio of reserves to production.

*Table 8: Data sources for coal reserves*

| Element | Data sources |
| --- | --- |
| **Proved reserves of coal** | • US Energy Information Administration (US EIA), International Energy Statistics (link)<br>• BGR (2020) |

The primary source of data on reserves is the US EIA International Energy Statistics database. The US EIA currently provides estimates of "recoverable reserves" of "hard coal" and "lignite" in 2014 (as of August, 2021). Previous estimates for 2005, 2008, and 2011 are used for gap-filling purposes if the most recent data are not available. In the US EIA statistics, data on the United States are from US government sources; data for other countries are from the World Energy Council (WEC). The WEC defines "proved recoverable reserves" as "resources remaining in known coal deposits that have been shown to be accessible under current local economic and technological conditions"[6]. The US EIA notes that proved reserves as defined by the WEC are analogous to what the administration calls "measured" reserves; however, the US EIA data on proved reserves of coal for the United States also include "indicated" reserves. The data for measured and indicated reserves for the United States "have been combined prior to depletion adjustments and cannot be recaptured as *'measured alone'*"[7]. The US EIA's data for "lignite" reserves are equal to the WEC's data for both lignite and sub-bituminous coal; the EIA data for hard coal is equal to the WEC data for bituminous coal including anthracite. The EIA data on reserves are thus consistent with the definitions of hard and brown coal according to the International Coal Classification of the Economic Commission of Europe.

The German BGR provides estimates of reserves of "hard coal" and "lignite" coal for 2018 (as of September, 2021). In the BGR estimates, reserves are defined as "proven volumes of energy resources economically exploitable at today's prices and using today's technology" (BGR 2015: 160)[8]. The BGR

[6] World Energy Council, "Energy Resources: Coal", https://www.worldenergy.org/data/resources/resource/coal/.

[7] US EIA, "International Statistics – Notes", http://www.eia.gov/cfapps/ipdbproject/docs/IPMNotes.html#c6.

[8] Note that while the WEC and BGR definitions of reserves are broadly consistent, the two institutions classify total resources differently. The WEC notes, "BGR's category 'resources' (using its own definition, which differs from WEC usage) amounts to around 82.9 billion tonnes of hard coal and 36.5 billion tonnes of lignite [for Germany]. These levels convey an indication of the enormous size of the additional amounts of coal 'in place', over and above the in-situ tonnages hosting the recoverable reserves" (WEC 2013). Because we are interested only in proven (or

definitions of hard coal and lignite differ from those used by the US EIA, WEC, IEA, and the International Coal Classification of the Economic Commission of Europe. Lignite is defined as "raw coal with an energy content (ash free) < 16,500 kj/kg," or about 3,900 kcal/kg. On the other hand, hard coal is any coal with an energy content of ⩾ 16,500 kj/kg, or with a heating value above 3,900 kcal/kg. Because of this definitional discrepancy, the BGR data on reserves are only used for gap-filling purposes for countries without US EIA and WEC data. Also, in using the BGR data to calculate the time to exhaustion of coal reserves, estimates are only made for countries for which the BGR has data on both reserves and production.

For countries without data on reserves, time to depletion is calculated using a simple average of the ratio of reserves to production for other countries in the region. An unweighted average is used because weighting would imply that the countries missing data are similar the world's major producers (e.g., R/P ratios for all East Asian countries are basically equivalent to those in China because China is the dominant producer in the region and accounts for about 55% of world coal production). Because there is no basis to judge the R/P ratios for missing countries, a simple unweighted average is better. Although this results in higher average R/P ratios, this suggests that countries with missing data are likely not extracting coal at the scale or rate of the major producers, which is logical.

The time to depletion that is calculated for the year in which data are available for both reserves and production (2014 for most countries) is assumed for all years. Also, as with other natural assets, the time to depletion for coal reserves is no longer capped at 25 years.

## C. Metals and minerals

Ten different metals and minerals are valued in the wealth accounts: bauxite, copper, gold, iron ore, lead, nickel, phosphate rock, silver, tin, and zinc. Many of the same data sources and estimation methods are used for all of the metals and minerals in the wealth accounts. Because of this, the following section describes the data sources and methods for metals and minerals as a group.

### 1. Production of metals and minerals

Data sources for the production of metals and minerals are listed in Table 9 below. Table 10 provides specific product definitions for each metal and mineral commodity.

For all metals and minerals, production data mostly come from the US Geological Survey's (USGS's) *Minerals Yearbook* and *Mineral Commodity Summaries*. Where data are missing in the USGS sources, data from the British Geological Survey (BGS) *World Mineral Statistics* archive may be used. In such cases, the following rules for gap-filling are applied. If USGS data are entirely missing for a country, the BGS data are used. If USGS data are available for some years but are missing for others, the BGS data may be used to

recoverable) reserves, the differences between how WEC and BGR categorize other resources (e.g., 2P and 3P) is not really relevant to us.

fill missing values only if there is general consistency between the USGS and BGS data. This means that the average difference between USGS and BGS statistics is within ±25 percent for years where there is overlap between the two sources.

*Table 9: Data sources for metals and minerals production*

| Element | Data sources |
|---|---|
| **Production of metals and minerals** | • US Geological Survey (USGS), Minerals Yearbook, Vol. I: Metals and Minerals, various years (link)<br>• USGS, Mineral Commodity Summaries, various years (link)<br>• British Geological Survey (BGS), World Mineral Statistics (link) |

*Table 10: Definitions for production of metals and minerals*

| Mineral | Definition for production statistics |
|---|---|
| **Bauxite** | Bauxite is “a naturally occurring, heterogeneous material composed primarily of one or more aluminum hydroxide minerals, plus various mixtures of silica, iron oxide, titania, aluminosilicate, and other impurities in minor or trace amounts” (1). BGS production statistics for bauxite may also include refractory bauxite for 1994 onwards. USGS statistics for Guinea, Guyana, and Jamaica are for the dry bauxite equivalent of crude ores. |
| **Copper** | USGS and BGS production statistics are for copper metal content, including the metal content from ores, concentrates, leaching, and electrowon copper. |
| **Gold** | USGS and BGS production statistics are for gold metal content. Data for some countries may include estimates of undocumented artisanal mining. |
| **Iron ore** | Iron ore production is reported by gross weight in both the USGS and BGS production statistics, where gross weight is the total for all iron products used in steelmaking. Data for some countries may include production of alternative iron sources such as nickeliferous iron ore, titaniferous magnetite beach sands, and manganiferous iron ore, and by-product ores. |
| **Lead** | USGS and BGS production statistics are for lead in concentrate, reported in terms of metal content. Data may include estimates of metal content of ores and of by-products from fluorspar and gold mining operations. |
| **Nickel** | USGS and BGS production statistics for nickel are reported for metal content. USGS statistics may include laterite ore, sulfate, sulfide concentrate, and ferronickel. BGS statistics may also the metal content of sulfates and concentrates. |
| **Phosphate rock** | USGS and BGS production data for phosphate rock may include apatite. Data are reported by gross weight. BGS data may also include lime phosphates and phosphate dust. Although BGS reports data for guano as part of phosphate production, these numbers are excluded. |

| | |
|---|---|
| **Silver** | USGS and BGS production statistics are for silver metal content. Data for some countries may include estimates of undocumented artisanal mining. |
| **Tin** | USGS and BGS production statistics are for tin metal content. USGS data may include content of tin-tungsten concentrate and estimates of artisanal production. |
| **Zinc** | USGS and BGS production statistics are for metal content and may include ores as well as zinc content in both lead and zinc concentrates |

*Sources: (1) USGS, Mineral Commodity Summaries; (2) BGS World Mineral Statistics data archive*

## 2. Mineral prices, costs, and unit rents

Unit rent of minerals is calculated at the mine level, using the S&P data for unit cost and the World Bank Global Economic Monitor (GEM) Commodities database (*"The Pink Sheet"*) for price. Although the S&P Global Market Intelligence database includes information on realized price at mine level, the GEM prices world price data after comparison confirmed consistency of prices in the two data sources. Use of GEM prices makes gap filling easier, increases transparency for data users, and eases future annual updates for the team, especially if S&P data are not accessible annually to the team. With high consistency between the two data sources, the benefits of using GEM prices outweighed any losses of information. For the purpose of calculating mineral rents, minerals fall into two categories based on availability of data from S&P Global Market Intelligence:

1. Minerals covered by USGS with coverage by S&P for at least some, but not all, countries (copper, gold, lead, zinc, iron ore, nickel, silver)
    a. Countries covered by S&P:
        i. S&P mine level data used to calculate unit rent, averaged to national level
    b. Countries not covered by S&P:
        i. Regional average unit rent
        ii. If regional average not available because S&P does not cover any country in the region, global average unit rent
2. Minerals covered by USGS but with no coverage by S&P (bauxite, tin, phosphate rock)

    For these countries we use a combination of current CWON unit rent estimates for the base year, and apply a new production cost index, replacing the old Manufactures Unit Value (MUV) index. The new cost index is derived from the change in average unit costs derived from the S&P data for the 7 minerals in 1.

The derivation of unit rents is discussed in two parts, corresponding to the two categories of minerals: the seven minerals with data from S&P and the three not covered by S&P.

### *Part 1: Calculating Total National Rents Based on USGS Production Data and S&P Unit Rent*

Total rents, $R_t^{M,N}$, for each mineral, M, in each country, N, are calculated as the product of the average unit rent, $\pi_t^{M,N}$, (derived in Part 2 and Part 3) and national production reported by USGS. USGS data for production and reserves are used instead of S&P data because S&P data are often not as complete as USGS data. By using the average national unit rent calculated from S&P data, we implicitly assume that S&P's 'missing' mineral output is produced at the same average unit cost and generates the same unit rent as the average for all S&P mines. This is discussed further in Part 2 and Part 3.

(2.7)
$$R_t^{M,N} = \pi_t^{M,N} q_t^{USGS,M,N}$$

where,

$R_t^{M,N}$ = Total rent for mineral, M, in country, N, in year t

$\pi_t^{M,N}$ = average unit rent for mineral, M, in country, N, based on S&P data in year t and GEM prices

$q_t^{USGS,M,N}$ = Total production of mineral, M, in country, N, from USGS/BGS data in year t

Annual rents calculated in this manner are then smoothed over 5 years and asset values, $V_t$, are then calculated using the following equation:

(2.8)
$$V_t = \sum_{i=t}^{t+T-1} \frac{\overline{R_t}}{(1+r)^{i-t}}$$

where,

$\overline{R_t}$ is a lagged, five-year moving average of annual total rents, $R_t$, in years *t* (the current year) to *t* – 4;

*r* is the discount rate (assumed to be a constant 4 percent), and

*T* is the lifetime of the resource.

## *Part 2: Unit Rent for Minerals Covered by S&P*

S&P covers 7 of the 10 minerals included in the CWON database. For each of these minerals, CWON requires national average unit rents in every year, 1991 to 2018. Unit rent calculation is carried out in two steps, first calculating unit rent at mine level, then averaging for national unit rents. Further averaging of unit rents across regions and globally is done for those countries identified by USGS as producers but missing from the S&P database; discussed in more detail below.

### Step 1. Unit Rent at Mine Level for Each Mineral

Unit rent, $\pi$, is calculated at the mine level, using the S&P data for unit cost and the World Bank Global Economic Monitor (GEM) Commodities database ("The Pink Sheet") for price[9].

(2.9) $$\pi_{m,t}^{M,N} = \left(p_t^{GEM,M} - c_{m,t}^{M,N}\right)$$

where,

$\pi_{m,t}^{M,N}$ = equals unit rent for mineral, M, in country, N, from mine, m, in year, t

$p_t^{GEM,M}$ = equals average global unit price in the GEM database for a mineral, M, in year t

$c_{m,t}^{M,N} = \frac{TC_{m,t}^{M,N}}{q_{m,t}^{SP,M,N}}$ unit cost is calculated from total cost and production in the S&P database

$TC_{m,t}^{M,N}$ = Total production costs for mine, m, year, t, for mineral M, in country N

$q_{m,t}^{SP,M,N}$ = Volume of production from S&P for mine, m, year, t, for mineral M, in country N

### Step 2. Unit Rent at National Level for Each Mineral

Average national unit rent, $\pi_t^{M,N}$ , is calculated by summing mine-level rent weighted by each mine's share of national production, as reported by S&P.

For each mineral, M = 1,…7:

(2.10) $$\pi_t^{M,N} = \sum_1^n \pi_{m,t}^{M,N} \times \frac{q_{m,t}^{SP,M,N}}{q_t^{SP,M,N}}$$

where,

Total S&P production at national level, $q_t^{SP,M,N}$, is the sum of production across all mines, m=1…n:

(2.11) $$q_t^{SP,M,N} = \sum_1^n q_{m,t}^{SP,M,N}$$

### Step 3. Unit Rent at Regional and Global Level

S&P has generally good country coverage, but it is not as complete as USGS; some countries are missing. The use of regional and global unit costs/rent for gap filling for missing data is commonly used. For the missing countries, we assume the unit rent for a given mineral is similar to the average unit rent for

[9] Price is expressed as dollars per tonne/ton/metric ton for paid copper, and dollars/troy ounce for paid gold.

producers of that mineral in countries that are covered by S&P. We apply the regional average unit rents for that mineral in the 'missing' countries.

Regional unit rents, $\pi_t^{M,Reg}$, are calculated as the weighted average of country unit rents with USGS production is used for country weights.

(2.12) $$\pi_t^{M,Reg} = \sum_1^n \pi_t^{M,N} \times \frac{q_t^{USGS,M,N}}{q_t^{USGS,M,Reg}}$$

where,

Total production at regional level is the sum of USGS production across all countries in the region, N=1…n:

(2.13) $$q_t^{USGS,M,Reg} = \sum_1^n q_t^{USGS,M,N}$$

For countries where there are no other producers in the region and a regional average cannot be calculated, a global average unit rent can be used. Calculating global averages is given by the following equations, noting that USGS production figures are used for weighting.

Global unit rents, $\pi_t^{M,G}$, are calculated as the weighted average of regional unit rents, with USGS production used for regional weights.

(2.14) $$\pi_t^{M,G} = \sum_1^m \pi_t^{M,R} \times \frac{q_t^{USGS,M,Reg}}{q_t^{USGS,M,G}}$$

where,

Total production at global level, $q_t^{USGS,M,G}$, is the sum of USGS production across all regions, R=1…m:

(2.15) $$q_t^{USGS,M,G} = \sum_1^m q_t^{USGS,M,N}$$

### Negative rents and the calculation of national average rents

Commodity prices are notoriously volatile and, in some cases, a mine in full operation may generate negative rents if the price falls below the cost of production. A mine may continue to operate under such conditions in the expectation that prices will rise in the future. Following the treatment recommended in the SEEA, negative rents are set to zero for the calculation of national unit rent. However, given the smoothing process that averages rents over five years, the rent in any given year is much less likely to be negative.

### *Part 3: Unit Rent for Minerals Not Covered by S&P*

S&P does not include information about three minerals in the CWON database: bauxite, tin, and phosphate rock. For these minerals, we propose a two-part approach:

1. *1991 base year unit cost*: continue using the 1991 base year unit cost estimated from case studies for earlier versions of CWON, but
2. *Updating unit cost for 1992-2018*: replace MUV to update the cost estimates with a cost index, $CI_t^G$ , based on S&P global average production costs, $c_t^{M,G}$. The index measures the change in annual production costs as a share of price, averaged over all minerals at global level. While this is far from ideal, it is an improvement over the MUV because the cost index is narrowly focused only on costs directly related to mining.

This cost index could be estimated in a manner similar to unit rents, by estimating costs at mine level and averaging across mines, countries, regions. A simpler method would take advantage of calculations already carried out to estimate global average unit costs implicit in the global average unit rent calculation. Global unit cost for each mineral could be expressed as:

(2.16) $$c_t^{M,G} = \left( p_t^{GEM,M} - \pi_t^{M,G} \right)$$

Because unit prices and units of measurement are so different across the seven minerals, we look at how **cost as a share of price** changes over time for each mineral, then average this change across all minerals:

(2.17) $$s_t^{M,G} = \left( c_t^{M,G} \div p_t^{GEM,M} \right)$$

where, $s_t^{M,G}$ is the global average cost share of S&P mineral, M, in year t, 1991…2018.

The global cost index, *CI^G^*, is calculated in two steps: first, a global cost index is calculated for each mineral, $CI^M$, then a simple, unweighted average of the change is taken across all minerals.

The cost index, $CI^M$, for each mineral, M, would simply be the change in cost from one year to the next, using the old CWON unit cost for 1991:

(2.18) $$CI_t^{M,G} = 1 + \left[ \frac{(s_t^{M,G} - s_{t-1}^{M,G})}{s_{t-1}^{M,G}} \right] \quad \text{for t = 1992...2018}$$

The global average cost index, $CI_t^G$, is the simple, unweighted average of unit costs across the seven minerals in S&P:

$$CI_t^G = \sum_1^7 CI_t^{M,G} \div 7 \tag{2.19}$$

The unit cost for each of the three non-S&P minerals would be calculated as:

- 1991: use unit cost from older versions of CWON, $c_{1991}^{M,Old}$
- 1992 to 2018: apply the global cost index for each year to the previous year's unit cost:

$$c_t^{M,G} = c_{t-1}^{M,G} \times CI_t^G \tag{2.20}$$

for t = 1992…2018 and

M = bauxite, tin, phosphate

Unit rent for these three minerals would then be $\pi_t^{M,G} = \left(p_t^{GEM,M} - c_t^{M,G}\right)$ and total rents calculated as in Part 1.

## 3. Mineral reserves and time to depletion

Years to exhaustion of the resource, *T*, are calculated given rates of current production and proven reserves. Data on reserves for all metals and minerals are from the USGS Minerals Yearbooks and Mineral Commodity Summaries, various years. USGS calculates reserves as that part of the reserve base which could be economically extracted or produced at the time of determination. The reserve base is defined as the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. Reserves (and mine production) data for selected countries (the largest producers) were available from 1994 onwards. Data for 1970 to 1993 are deduced from averages over the years for which data are available. For resources in countries for which production data are available but information on reserves is absent, regional or world averages for *T* are used.

# III. Forest Resources

The total value of forest resources as estimated for the World Bank wealth accounts includes the capitalized value of rents from timber, along with the value of non-timber forest ecosystem services. Data and methods for estimating the value of timber and non-timber services are described below.

## A. Timber resources

The predominant economic use of forests has been as a source of timber. Timber resources are valued according to the present discounted value of rents from the production of roundwood over the expected lifetime of standing timber resources. This value, $V_t$, is given by the following equation:

(3.1)
$$V_t = \sum_{i=t}^{t+T-1} \frac{\bar{R}_t}{(1+r)^{i-t}}$$

where $\overline{R_t}$ is a lagged, five-year moving average of rents from timber in years *t* (the present year) to *t* – 4; *r* is the social discount rate (assumed to be equal to 4 percent), and *T* is the lifetime of timber resources capped at 100 years. Unlike metals and minerals, timber is a renewable resource, so *T* depends on the rate of timber extraction relative to natural rates of forest growth and resource replacement. Rents from timber in year *i* are calculated as:

(3.2)
$$R_t = \pi_t Q_t$$

where $\pi_i$ denotes unit rents, equal to revenues less production costs; and $Q_i$ denotes the quantity of roundwood extracted. Data and methods for estimating timber wealth are described below. Rents are converted into units of constant US dollars at market rates using country-specific GDP deflators before averaging to obtain $\bar{R}$.

### 1. Timber production

Data on annual roundwood production are obtained from the FAOSTAT database maintained by the Food and Agricultural Organization of the UN (FAO) (Table 11). As defined by FAO, roundwood production "comprises all wood obtained from removals, i.e., the quantities removed from forests and trees outside the forest, including wood recovered from natural, felling, and logging losses…" (FAO 2014: xx)[10]. Total roundwood production, *Q*, is equal to the sum of the production of industrial roundwood, $q_{industry}$, and woodfuel, $q_{fuel}$:

(3.3)
$$Q = q_{\text{industry}} + q_{\text{fuel}}$$

[10] FAO, *FAO Yearbook of Forest Products 2012*, http://www.fao.org/forestry/statistics/80570/en/.

Industrial roundwood is "wood in the rough" and comprises "all roundwood used for any purpose other than energy," including pulpwood, sawn logs, veneer logs, and other types of roundwood such as fence posts and telephone poles[11]. Industrial roundwood includes both coniferous and nonconiferous stocks of roundwood. Woodfuel is "all roundwood that is used as fuel for purposes such as cooking, heating, or power production, and it includes wood that is used to make charcoal"[12]. Roundwood production is measured in terms of volume (cubic meters).

*Table 11: Data sources for timber production*

| Element | Data sources and notes |
|---|---|
| **Roundwood production** | • Data from UN Food and Agricultural Organization (FAO), FAOSTAT database (link)<br>• Roundwood production is the sum of coniferous industrial roundwood (FAO item code 1866), nonconiferous industrial roundwood (item 1867), and woodfuel (item 1864) |

For a number of countries missing data from FAO, timber production is assumed to be zero for all years. These countries include small island economies, city states, and others for which commercial timber production is deemed to be negligible:

*Table 12: Economies with missing data that are assumed to have zero timber production for all years (1970-2018)*

| Country/Economy |
|---|
| **Antigua and Barbuda** |
| **Bermuda** |
| **Cabo Verde** |
| **Greenland** |
| **Grenada** |
| **Hong Kong SAR, China** |
| **Isle of Man** |
| **Monaco** |
| **St. Kitts and Nevis** |
| **Macao SAR, China** |
| **Marshall Islands** |
| **Palau** |

[11] FAO, "2012 Global Forest Products Facts and Figures," December 2013, http://www.fao.org/forestry/statistics/80938/en/.

[12] FAO, "2012 Global Forest Products Facts and Figures," December 2013, http://www.fao.org/forestry/statistics/80938/en/.

| | |
|---|
| **Puerto Rico** |
| **San Marino** |
| **Syrian Arab Republic** |
| **Tuvalu** |
| **West Bank and Gaza** |

For other countries, the FAO may have data on production for some years, but not others. In this case, if there is zero production value for the earliest year of data for that country, then production is assumed to also be zero in all earlier years for which data are missing. Countries and years for which zero production values are gap-filled in this way include:

*Table 13: Additional economies for which zero timber production is assumed for some years*

| Country | Years filled with zero values |
|---|---|
| **Andorra** | 1995-2008 |
| **Faeroe Islands** | 1995-2008 |
| **Iceland** | 1995-1997 |
| **Malta** | 1995-1997 |
| **Tajikistan** | 1995-1997 |

Coverage for Europe and Central Asian countries prior to 2000 in the FAO database is spotty. There are a number of countries that are only missing data on timber production for 1995-1997. In addition to those countries with missing timber production values already listed in Table 12 and Table 13 above, European and Central Asian countries with missing data for 1995-1997 include Armenia, Azerbaijan, Georgia, Kyrgyz Republic, Turkmenistan, and Uzbekistan. For these countries, missing timber production data for 1995-1997 are gap-filled by assuming values for 1998. Values in 1998 for overharvest and unit rents are also assumed for 1995-1997.

Finally, for years prior to 2000, the FAO reported data on timber production in Belgium and Luxembourg together as for "Belgium-Luxembourg." Production and trade values for Belgium and Luxembourg in the years prior to 2000 are allocated to the two countries according to their respective shares in total timber production for Belgium and Luxembourg in 2000.

### 2. Timber prices and unit rents

Unit resource rents, $\pi$, are calculated as the average export unit value for roundwood, $E$, weighted by production volume, multiplied by a rental adjustment factor, $a$:

(3.4) $$\pi = E \cdot a$$

The export unit value is the total value of exports divided by total volume of exports, and is calculated using data from FAOSTAT (Table 14). Estimates of *E* are constructed using regional averages, which helps correct for the observed volatility in prices at the country level. In calculating *E*, outliers are excluded such that if *E* for country *i* exceeds the sum of the third quartile plus 1.5 times the interquartile range (i.e., third quartile minus first quartile), it is replaced with the world median value.[13]

*Table 14: Data sources for estimating timber prices and unit rents*

| Element | Data sources and notes |
|---|---|
| **Roundwood export volume** | • Data from UN Food and Agricultural Organization (FAO), FAOSTAT database (link) |
| **Roundwood export value** | • Data from UN Food and Agricultural Organization (FAO), FAOSTAT database (link) |
| **Rental adjustment factor** | • Estimates by Applied Geosolutions (2016) |

The rental adjustment factor, *a*, is equal to the ratio of unit rents to the export unit value. The adjustment factor takes into account the average difference between domestic stumpage prices for timber and export log values for countries in that region, given production costs (Applied Geosolutions 2016). Adjustment ratios are estimated using data on domestic timber prices for the countries and regions indicated in Table 15 below. Production costs are taken as the sum of harvesting, skidding and loading, and transportation costs. Because data on timber production costs in countries around the world are not readily available, costs are estimated indirectly by calculating costs for typical harvesting operations in the United States and then adjusting for differences in labor costs and the overall productivity in the economy that are thought to influence domestic production costs. Also, because data on log prices are not available for any countries in the Middle East and North Africa region, the rental adjustment factor for this regional is estimated as the simple average of the adjustment factors for all other regions. The rental adjustment factor is assumed to be constant over time. Country-specific rental adjustment factors are applied where available. For all other countries, regional averages are assumed. Average export unit values, rental adjustment ratios, and unit rents for timber by region are presented in Table 15. Average values shown in the table are weighted by production.

[13] This method to exclude and replace outliers is consistent with the method for calculating crop export unit values in the World Bank's *Changing Wealth of Nations* (2018).

*Table 15: Average export unit values and unit rents for timber by region in 2018*

| ***Region/country name*** | ***A = Export unit value (US$/m3)*** | ***B = Unit rent (US$/m3)*** | ***Rental adjustment factor (B/A)*** |
|---|---|---|---|
| **Sub-Saharan Africa** | **117** | **48** | **0.41** |
| Ghana | 108 | 45 | 0.41 |
| Other | 117 | 48 | 0.41 |
| **East Asia and Pacific** | **185** | **42** | **0.23** |
| Australia | 176 | 48 | 0.27 |
| China | 190 | 32 | 0.17 |
| Indonesia | 234 | 33 | 0.14 |
| Malaysia | 281 | 325 | 1.15 |
| New Zealand | 75 | 29 | 0.39 |
| Other | 164 | 43 | 0.26 |
| **Eastern Europe and Central Asia** | **81** | **21** | **0.26** |
| Russian Federation | 80 | 21 | 0.26 |
| Other | 84 | 22 | 0.26 |
| **Western Europe** | **94** | **18** | **0.20** |
| Finland | 99 | 14 | 0.15 |
| Germany | 94 | 18 | 0.19 |
| Other | 93 | 19 | 0.21 |
| **Latin America and Caribbean** | **158** | **37** | **0.23** |
| Argentina | 141 | 27 | 0.19 |
| Brazil | 179 | 42 | 0.23 |
| Chile | 129 | 23 | 0.18 |
| Costa Rica | 158 | 108 | 0.68 |
| Guyana | 161 | 155 | 0.96 |
| Other | 136 | 33 | 0.24 |
| **Middle East and North Africa** | **98** | **22** | **0.22** |
| **North America** | **144** | **17** | **0.12** |
| Canada | 148 | 9 | 0.06 |
| United States | 143 | 20 | 0.14 |
| **South Asia** | **102** | **10** | **0.10** |
| India | 104 | 11 | 0.10 |
| Other | 94 | 9 | 0.10 |

*Note:* Countries listed in table are those for which rental adjustment factors are calculated from the ratio of domestic stumpage prices to export unit values by Applied Geosolutions (2016). Regional values and other are calculated as the weighted average with respect to timber production. The rental adjustment factor for the Middle East and North Africa is a simple average of all other regions' factors.

*Source: Rental adjustment factors estimated by Applied Geosolutions (2016); export unit values estimated using data from FAO, FAOSTAT database*

### 3. Lifetime of timber resources

The lifetime over which timber resources is determined by the rate of timber extraction (*Q*) relative to the rate of natural growth (*N*). If $Q > N$, then current rates of extraction are unsustainable, and the lifetime of the resources is limited. If $Q \leqslant N$, then extraction is assumed to be sustainable, and the lifetime of the resource is taken as infinite. As with for other assets, *T* is no longer capped at 25 years.

Data sources for estimating *T* are listed in Table 16 below.

*Table 16: Data sources for estimating the lifetime of timber resources*

| Element | Data sources and notes |
|---|---|
| **Total forest area** | • FAO, *Global Forest Resources Assessment* (link) |
| **Production forest area** | • FAO, *Global Forest Resources Assessment* (link) |
| **Multiple use forest area** | • FAO, *Global Forest Resources Assessment* (link) |
| **Net annual increment** | • FAO, *Global Forest Resources Assessment* (link)<br>• Estimates by World Bank forestry experts |
| **Growing stock of timber** | • FAO, *Global Forest Resources Assessment* (link) |

Natural growth *N* is calculated using data from the FAO's *Global Forest Resources Assessment* (FRA) for 2015[14] and is given by $N = A \cdot I$, where *A* is the area of productive forest and *I* is the average net annual increment. Productive forest area is defined in the FRA as "forest area designated primarily for production of wood, fibre, bio-energy and/or non-wood forest products" (FAO 2012: 11). FRA also provides the area of "multiple use" forests, which the FRA defines as "forest area designated primarily for more than one purpose and where none of these alone is considered as the predominant designated function" (FAO 2012: 11). To minimize discrepancies across countries given different definitions of multiple use, starting with CWON 2021, the area of timber forest is estimated by subtracting from the total forest area those forests located within protected areas, excluding protected area categories that could be used for sustainable timber production (i.e., protected areas in IUCN categories V and VI). Total forest area includes the area of all "[l]and spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more

[14] Data from the FRA 2015 may be obtained from FAO, "Global Forest Resources Assessment", http://www.fao.org/forest-resources-assessment/en/.

than 10 percent, or trees able to reach these thresholds *in-situ"* and excludes "land that is predominantly under agricultural or urban land use" (FAO 2012: 3)[15].

Data on net annual increment *I* are also obtained from the FAO's FRA 2015. Net annual increment is defined in the FRA as "average annual volume of gross increment over the given reference period less that of natural losses on all trees, measured to minimum diameters as defined for 'growing stock'" (FAO 2012: 9). Where estimates of net annual increment are not available from the FRA, previous estimates of annual increment by World Bank forestry experts are used instead.16 As with the data on total forest area, the FRA data on net annual increment are in five-year intervals. Estimates for in-between years are interpolated linearly. For countries where FRA estimates of net annual increment are available, data for earlier years (before 1990) are extrapolated by assuming the country value for average annual increment in 1990. Net annual increment for any additional countries not covered in the FRA or the World Bank estimates is assumed to be equal to the regional average for countries with data.

The growing stock of timber in forests designated for marketable production is estimated by assuming that the growing stock of timber per hectare of production-designated forests is equal to the average growing stock per hectare of total forest area. Data on the growing stock of timber are obtained from the FAO's FRA 2015. To estimate the growing stock of timber in production-designated forests for years

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[15] Note that estimates for forest area prior to 1990 should be treated with caution. For a considerable number of countries, old FAO estimates for forest area in 1970 and 1980 (which are pulled in from previous years' ANS data) are much lower or much higher than the FAO's FRA estimates for years after 1990. These old data for 1970, 1980, and 1990 were obtained from previous work done in the World Bank. This work obtained the area figures for most tropical countries from K. D. Singh of the United Nations Food & Agriculture Organization, for most temperate countries from FAO (1994), and for Former Soviet Union countries from Sten Nilsson of the International Institute for Applied Systems Analysis in Vienna. Some additional data were collected from WRI (1995). The lack of comparability between the old forest area data and the FRA estimates is demonstrated, for example, by the figures for South Africa, where total forest area for 1980 is shown as 4.15 million hectares (ha) in the old data and is shown as 9.24 million ha in the FRA numbers. It is also 9.24 million ha in the FRA for all years after 1990, so it seems unlikely that forest area doubled in ten years between 1980 and 1990. Because of the dramatic increase between 1980 and 1990, the interpolated estimates for forest area prior to 1980 plummet to zero. This raises the question of where the methodology for estimating total forest area was the same for years prior to 1990 as it was for the FRA. To correct for this, in cases where countries' total forest area is less than zero in 1970 or where total forest area in 1980 is less than 50% or more than 200% what it is in 1990, the old FAO data for 1970 and 1980 is disregarded, and values for total forest area are interpolated by applying a linear trend using the data for all years after 1990. This correction applied to the following countries: Alteria, Angola, Aruba, The Bahamas, Cape Verde, Comoros, Drijbouti, El Salvador, Eritrea, Faeroe Islands, The Gambia, Greenland, Grenada, Guam, Haiti, Kazakhstan, Kenya, Kiribati, Lesotho, Libya, Malta, Marshall Islands, Fed. Sts. Micronesia. Mozambique, Northern Mariana Islands, Oman, Seychelles, Singapore, South Africa, St. Lucia, Swaziland, Togo, Turkey, United Arab Emirates, Vanautu, Virgin Islands (U.S.), Rep. Yemen, and Zimbabwe.

[16] Previous estimates by the World Bank are for *commercial* annual increment, which is the "average standing volume of commercial-quality wood mass grown per hectare per year." The FAO measure of net annual increment does not make a distinction for commercial-quality growth.

prior to 1990, the average stock per hectare of forest in 1990 is assumed. If $Q > N$ (that is, if current rates of timber extraction are unsustainable), then the number of years to the exhaustion of a country's timber resources $T$ is estimated by dividing the growing stock of timber in production-designated forest by the volume of timber that is harvested unsustainably ($Q - N$). This method of calculating the lifetime of the resource assumes that current rates of extraction remain constant and that the total growing stock of timber and area of forest do not *change* except for the loss of timber due to overharvesting.

## B. Forest ecosystem service values

In addition to timber production, forests provide a range of services that are vital to the economy. Nontimber forest benefits—ecosystem services—such as nonwood forest products, hunting, recreation, and watershed protection are significant benefits not usually accounted for, which leads to the undervaluation of forest resources. This edition of The Changing Wealth of Nations builds upon the forest ecosystem services wealth introduced in the previous wealth report and presents results from the updated meta-analysis study that predicts annual, per hectare values for each service category per country based upon a spatially explicit meta-regression model (Siikamäki et al. 2021). Compared to the previous report, this updated study broadens the coverage of forest ecosystem service values and employs machine learning algorithms in its predictive models. Additionally, the study now provides a time series of ecosystem services values. Data sources for valuing non-timber forest ecosystem services are summarized in Table 17.

*Table 17: Data sources for estimating the value of non-timber forest ecosystem services*

| Element | Data sources and notes |
|---|---|
| **Total forest area** | • FAO, *Global Forest Resources Assessment* (link) |
| **Annual service values per hectare of forest** | • Unit values are as estimated by Siikamäki, J., et al (2021)<br>• Annual values equal the sum of: recreation, hunting, and fishing; non-wood forest products (NWFP); and watershed protection. |

Three main categories of non-wood forest ecosystem services are considered: (i) recreation, hunting, and fishing; (ii) non-wood forest products (NWFP); and (iii) watershed protection. Annual, per-hectare values for each service category are determined for individual countries per the results of a meta-analysis by Siikamäki et al. (2021). The authors analyzed 498 studies of non-wood forest benefits to develop a spatially explicit meta-regression model that predicts service values for 10km x 10km plots of forest around the globe.

The meta-regression estimation data set in Siikamäki et al. (2021) includes values from 53 countries on five continents. The most represented regions are Europe, North America, South America, and Southeast Asia. All the continents with forests and all the different forest biomes—humid tropics, dry tropics, temperate, and boreal—are represented. Socioeconomic, biophysical, climate, ecological extent, and ecological condition variables were constructed to estimate the global spatially explicit predictions of the different forest ecosystem services. The total value of forest ecosystem services per country is computed by multiplying the combined per hectare value of recreation, nonwood forest products, and water services by the total forest area per country, measured using official international forest statistics from FAO. Where country-level estimates are unavailable from Siikamäki et al. (2021), regional averages are applied. Table 18 reports average annual service values by region for the three different service categories.

*Table 18: Annual value of non-timber forest ecosystem services in 2018 (in 2018 US$ per hectare)*

| Region | Recreation, hunting, fishing | Watershed protection | NWFP | Total annual value |
|---|---|---|---|---|
| **East Asia & Pacific** | 155.70 | 32.41 | 11.51 | 274.23 |
| **Europe & Central Asia** | 52.00 | 41.55 | 5.56 | 161.63 |
| **Latin America & Caribbean** | 75.64 | 18.52 | 6.70 | 132.44 |
| **Middle East & North Africa** | 234.87 | 16.41 | 9.80 | 360.31 |
| **North America** | 343.35 | 57.97 | 6.17 | 511.25 |
| **South Asia** | 162.91 | 5.90 | 23.62 | 226.11 |
| **Sub-Saharan Africa** | 63.39 | 5.95 | 20.49 | 112.16 |
| **World** | 132.71 | 33.13 | 8.70 | 234.94 |

Note: NWFP = non-wood forest products.
*Source: Siikamäki et al. (2021)*

The annual value of non-timber forest ecosystem services is estimated by multiplying total forest area by the sum of the per-hectare monetary values for the three benefit categories. The capitalized value of ecosystem services is equal to the present value of annual services, discounted over 100 years. The present value of non-timber services is given by the following equation:

$$PV(S) = \sum_{i=1}^{i=100} \frac{S\,x\,F}{(1+r)^i} \quad (3.5)$$

where *S* is the sum of per-hectare service values for the three benefit categories, F is the total forest area; and *r* is the social discount rate of 4 percent. Services received during present year are not discounted. No distinction is made between natural and planted forest. Per-hectare monetary values estimated for 2018 are assumed to be constant over time and are adjusted for inflation using country specific GDP deflators. Also, values are estimated for the current forest area, assuming no change in forest cover in the future.

# IV. Agricultural Land

Agricultural land constitutes a considerable portion of total wealth in developing countries, particularly in the low-income group. For the purposes of the World Bank wealth accounts, agricultural land is conceptually divided into cropland and pastureland. There are potentially two alternative methods for estimating land wealth. The first method uses information from sales of land. The second method uses information on the annual flow of rents the land generates and takes the present value of such rents in the future. Given that information on land transactions is often missing, the second method is used. The value of cropland and pastureland is calculated as the present value of crop and pasture rents, discounted over 100 years.

### *Cropland*

For the first time, this wealth report accounts for the impact of soil degradation and climate change on future crop yield growth rates. Gerber et al. (2021) generated new country-specific crop yield growth rates estimated at the grid-cell level, accounting for the impacts future changes in precipitation, temperature, and degradation (driven by salinization, unsustainable irrigation, and erosion). This is an improvement over CWON 2018, which assumed fixed crop production growth rates. Future crop production is based on projections of the yields of 10 major crops which together comprise 83 percent of calories produced on cropland.

*Annual resource rents* for a given year, $TR_{c,t}$, are the sum of the rents, $R_{c,k,t}$, for each crop, k, in each country, c, in a given year, t. Rents are the product of price (p), quantity(q) produced and a rental rate parameter:

(4.1) $$TR_{c,t} = \sum_{k=1}^{n} R_{c,k,t}$$

where

(4.2) $$R_{c,k,t} = \left(p_{c,k,t} \times q_{c,k,t} \times a_{Reg}\right)$$

for

c = country,

k = 1,…,n for number of crops covered by FAO,

t = 1995 to 2018, or latest year available,

$a_{Reg}$ = average rental rate across all crops in a region, Reg = 1,…,14, Reg, as defined by Evenson and Fuglie (2010) used for rental rates. The rental rate is the ratio of (price – cost) / price. The rental rate is not given a *t* subscript because it is assumed to be constant over time.

In each year*, p x q* = FAO's Gross Value of Production (GVP), with *p* and *q* as 5-year lagged averages, not annual values. Because we do not have separate rental rates for each crop, k, or for every year, t, the equations can be implemented using FAO data for Gross Value of Production (GVP):

(4.3)
$$TR_{c,t} = GVP_{c,t} \times \alpha_{Reg}$$

*Asset value,* $V_{c,\tau}$ is calculated as the discounted sum of total rents over the lifetime, T=100 years, with a discount rate, r, of 4%, but the annual net growth is now estimated annually for each of 10 major crops, k, in each country, c. Growth can vary over time (with a limit on unconstrained growth) for each of the 10 crops (in contrast to the CWON 2018 approach which assumed continuous growth).

Going forward, instead of using growth rate g we introduce a growth factor $\gamma$. This change is motivated by the fact that the growth factor can vary from year to year, rendering the term $(1+g)^t$ difficult to generalize. If we introduce the growth factor $\gamma$, it is easy to relate to the $(1+g)^t$ term for the case of constant $(1+g)^t$ :

(4.4)
$$Increase\ in\ yield\ in\ year\ t\ = \gamma_t = (1+g)^t$$

For the case where yearly growth factor is not constant, we have

(4.5)
$$Increase\ in\ yield\ in\ year\ t = \gamma_t = \prod_{i=1}^{t}(1+g_i)^t$$

Although we continue to use the term 'growth' for the parameter, $\gamma$, it is possible that there is actually a decline in the change of yield over time and $\gamma$ could be less than 1. Three separate impacts on growth are estimated: crop yield trend due to technical improvements, $\gamma_{c,k,t}^{yt}$ , climate change impact on yields, $\gamma_{c,k,t}^{CC}$ , and land degradation impacts on yield, $\gamma_{c,k,t}^{LD}$ ,which can result from multiple causes such as soil erosion, salination, etc. (see details on the model in Gerber et al. 2021)

*crop technical yield trend* (+ or -), $\gamma_{c,k,t}^{yt}$

*climate change impact* (+ or -), $\gamma_{c,k,t}^{CC}$

*land degradation impact* (-), $\gamma_{c,k,t}^{LD}$

(4.6)
$$\gamma_{c,k,t}^{Y} = \gamma_{c,k,t}^{yt}\gamma_{c,k,t}^{CC}\gamma_{c,k,t}^{LD}$$

Estimation of $\gamma$ starts with estimation of annual crop yield growth due to technical change, $\gamma^{yt}$ , which is then adjusted for the impacts on yield of climate change and land degradation.

The individual yield growth factors, $\gamma^{Y}_{c,k,t}$, are calculated for each of the 10 major crops and are then aggregated to country and regional average yield growth rates and applied to FAO's Gross Value of Production (GVP), discussed below.

The CWON asset valuation method requires a *national level* average annual production growth factor that can be applied to FAO's Gross Value of Production (GVP). The production growth factor is the product of the yield growth factor $\gamma^{Y}_{c,t}$, and an area growth factor. In the analysis by Gerber et al. 2021, cropped area is held constant over time (so the area growth factor = 1.0).

Yield growth factors are calculated based on 10 crops which together constitute some fraction F of each country's agricultural production value. If that fraction F is 100%, the national yield growth can be calculated as the annual weighted yield growth factor for each crop, $\gamma^{Y}_{c,k,t}$, with weights supplied by the value share of production for each crop. This approach would be reasonably accurate even when the 10 crops account for less than 100% of GVP, but still comprise a 'substantial' share. At the other extreme, a country might not produce any of the 10 crops covered in the estimation. Rules for estimating national yield curves are needed in such countries.

CWON often uses 'regional' averages for gap filling or when the country-level information is not sufficient to provide a reasonable estimate. To determine whether country or regional average yields should be used, Gerber et al. (2021) examine how much the 10 crops--mostly cereals, grains and oil crops—account for a country's GVP.

The 10 crops represent a large share of *land area* under cultivation in many countries, but account for a smaller share of the *value* of agricultural production, GVP. Over the period 2011-2016 the average share of the 10 crops in GVP ranges from 0 to 100% across countries, and averages 42% at the global level. The 10 crops accounted for at least 50% of GVP in only 43 countries. Given the limited share of the 10 crops in many countries, Gerber et al. (2021) calculate regional average growth rates to apply at the country level. This approach is less than perfect but still an improvement over the estimates in earlier versions of CWON.

In practice, crop-weighted growth-rate parameters are calculated and presented at both the country and regional levels. To guide the decision about which parameter to use, a calculation was made and presented for every country of the fraction of 2016 values for the 10 crops to total GVP, and a decision can be made globally or regionally on what minimum value of the value ratio is required to use for the country-specific growth rate.

Regional average yield growth factor $\gamma^{Y}_{Reg,t}$ , is derived from country-level estimates, weighted by the value of the 10 crops for which yield growth is estimated. This is done in two steps: first calculating national weighted average yield growth factors, $\gamma^{Y}_{c,t}$ then calculating regional averages with country weights for the 10 crops over the *n* countries in each region. National level weights for each crop are calculated based on the 10-year best-fit of time series of agricultural value obtained from FAO.

Average yield growth at the national level is calculated as the average of yield growth rates for each crop weighted by that crop's value of production:

(4.7) $$\gamma_{c,t}^{y} = \sum_{k=1}^{10} \gamma_{c,k,t}^{y} \times {p_{c,k,t} q_{c,k,t}}/{GVP_{c,t}^{C10}}$$

where,

$GVP_{c,t}^{C10}$ is the sum of production across the 10 crops, k=1…10.

(4.8) $$GVP_{c,t}^{C10} = \sum_{k=1}^{10} p_{c,k,t} \times q_{c,k,t}$$

Regional average yield growth is calculated as:

(4.9) $$\gamma_{Reg,t}^{Y} = \sum_{c=1}^{n} \gamma_{c,t}^{Y} \times {GVP_{c,t}^{C10}}/{GVP_{Reg,t}^{C10}}$$

where

(4.10) $$GVP_{Reg,t}^{C10} = \sum_{c=1}^{n} GVP_{c,t}^{C10}$$

The value of agricultural land is calculated as the discounted total rents, TR, with annual growth (relative to year 2018) of $\gamma_{Reg,t}^{Y}$ or $\gamma_{c,t}^{Y}$, over a lifetime of 100 years.

Regionally aggregated of growth rates:

(4.11) $$V_{c,\tau} = \sum_{t=\tau}^{\tau+100} {TR_{c,t} \times \gamma_{Reg,t}^{Y}}/{(1+r)^t}$$

Country-aggregated growth rates:

(4.12) $$V_{c,\tau} = \sum_{t=\tau}^{\tau+100} {TR_{c,t} \times \gamma_{c,t}^{Y}}/{(1+r)^t}$$

*Pastureland*

Similar to cropland the the resource rent equation can be implemented using FAO data for Gross Value of Production (GVP) and regional rental rates:

(4.13) $$TR_{c,t} = GVP_{c,t} \times \alpha_{Reg}$$

Pastureland asset value, $V_{c,\tau}$ is then calculated as the discounted sum of total rents over 100 years, with a discount rate, r, of 4 percent

(4.14) $$V_{c,\tau} = \sum_{t=\tau}^{\tau+100} TR_{c,t} \times (1+g_d)^t \Big/ (1+r)^t$$

This assumes that total rents grow annually at the rate, $g_d$ . For livestock products, future rents are assumed to grow at a fixed annual rate of 1.475 percent for low- and middle-income countries and 0.445 percent for high-income countries, half of previously assumed in CWON 2018 for consistency with lower land productivity assumed in cropland.

Total rents are converted into units of constant US dollars at market rates using country-specific GDP deflators. The area of agricultural land is assumed to be constant; that is, wealth is estimated for the current area of land, not considering changes in the area of land that may affect rents in the future.

## A. Production of crops and livestock products

Data on the production of crop and livestock products for valuing agricultural land are obtained from the FAO, as indicated in Table 19. Primary crop and livestock products that are included in the estimation of returns from land are listed in Table 20 and Table 21:. Processed agricultural goods are not considered; however, there are some crops such as oil palm fruit and seed cotton for which the FAO also treats their derivative products as primary crops (e.g., palm oil and palm kernels, cotton lint, and cottonseed). Production is counted for the calendar year in which the entire harvest or the bulk of it took place. Cereal production is for dry grain only, meaning that cereals harvested for animal feed or silage are excluded. Vegetable production is also limited to products intended mainly for human consumption. Household production for self-consumption (e.g., in small gardens) is generally not counted due to limitations in the reporting of official statistics. Data on fruit production are for fresh fruit and may include fruit intended for direct consumption or for processing into other products such as jams, wine, juice, etc. Data on fruits is mainly limited to plantation or orchard crops for sale. As for livestock products, data on meat products are limited to indigenous production (i.e., animals that are raised within the country, excluding animals that are raised elsewhere and then imported for slaughter)[17].

[17] For more details on crop and livestock production statistics, please refer to the methods and standards of the FAO FAOSTAT database, http://faostat3.fao.org/mes/methodology_list/E.

*Table 19: Data sources for crop and livestock production*

| Element | Data sources and notes |
|---|---|
| **Primary crop and livestock production** | • FAO, FAOSTAT database (link) |

*Table 20: Crop products included in valuing agricultural land*

| Category | Crops | | |
|---|---|---|---|
| ***Cereals*** | Barley | Maize | Rye |
| | Buckwheat | Millet | Sorghum |
| | Canary seed | Oats | Triticale |
| | Cereals, nes | Quinoa | Wheat |
| | Fonio | Rice, paddy | |
| ***Fibers*** | Agave fibers nes | Flax fiber and tow | Ramie |
| | Bastfibres, other | Hemp tow waste | Sisal |
| | Coir | Jute | |
| | Fiber crops nes | Manila fiber (abaca) | |
| ***Fruits*** | Apples | Fruit, citrus nes | Papayas |
| | Apricots | Fruit, fresh nes | Peaches and nectarines |
| | Avocados | Fruit, pome nes | Pears |
| | Bananas | Fruit, stone nes | Persimmons |
| | Berries nes | Fruit, tropical fresh nes | Pineapples |
| | Blueberries | Gooseberries | Plantains |
| | Carobs | Grapefruit (inc. pomelos) | Plums and sloes |
| | Cashewapple | Grapes | Quinces |
| | Cherries | Kiwi fruit | Raspberries |
| | Cherries, sour | Lemons and limes | Strawberries |
| | Cranberries | Mangoes | Tangerines |
| | Currants | Mangosteens | Mandarins |
| | Dates | Guavas | Clementines |
| | Figs | Oranges | Satsumas |
| ***Nuts*** | Almonds, with shell | Chestnut | Pistachios |
| | Brazil nuts, with shell | Hazelnuts, with shell | Walnuts, with shell |
| | Cashew nuts, with shell | Nuts, NES | |
| ***Oil crops*** | Castor oil seed | Melonseed | Seed cotton |
| | Coconuts | Mustard seed | Sesame seed |
| | Groundnuts, with shell | Oil, palm fruit | Soybeans |
| | Hempseed | Oilseeds, NES | Sunflower seed |
| | Jojoba seed | Olives | Tallowtree seed |
| | Kapok fruit | Poppy seed | Tung nuts |

| | | | |
|---|---|---|---|
| | Karite nuts (sheanuts) | Rapeseed | |
| | Linseed | Safflower seed | |
| **Pulses** | Bambara beans | Cow peas, dry | Pigeon peas |
| | Beans, dry | Lentils | Pulses, NES |
| | Broad beans, horse beans, dry | Lupins | Vetches |
| | Chick peas | Peas, dry | |
| ***Roots*** | Potatoes | Sweet potatoes | Yams |
| | Roots and tubers, nes | Taro (cocoyam) | Yautia (cocoyam) |
| **Spices** | Anise, badian, fennel, coriander | Ginger | Pyrethrum, dried |
| | Areca nuts | Hops | Rubber, natural |
| | Chilies and peppers, dry | Nutmeg, mace and cardamoms | Spices, NES |
| | Cinnamon (canella) | Pepper (piper spp.) | Vanilla |
| | Cloves | Peppermint | |
| ***Stimulants*** | Chicory roots | Kola nuts | Tobacco, unmanufactured |
| | Cocoa, beans | Maté | |
| | Coffee, green | Tea | |
| ***Sugar*** | Sugar beet | Sugar cane | Sugar crops, NES |
| ***Vegetables*** | Artichokes | Eggplants (aubergines) | Onions, shallots, green |
| | Asparagus | Garlic | Peas, green |
| | Beans, green | Leeks, other alliaceous vegetables | Pumpkins, squash and gourds |
| | Cabbages and other brassicas | Lettuce and chicory | Spinach |
| | Carrots and turnips | Maize, green | String beans |
| | Cassava | Melons, other (inc. cantaloupes) | Tomatoes |
| | Cauliflowers and broccoli | Mushrooms and truffles | Vegetables, fresh NES |
| | Chilies and peppers, green | Okra | Vegetables, leguminous NES |
| | Cucumbers and gherkins | Onions, dry | Watermelons |

Notes: NES = not elsewhere specified.

*Source: Crops included in FAO, FAOSTAT database.*

*Table 21: Livestock products included in valuing agricultural*

| Category | Livestock products | | |
|---|---|---|---|
| ***Meat*** | Ass | Goat | Other camelids |
| | Buffalo | Horse | Game |
| | Camel | Mule | |
| | Cattle | Sheep | |
| ***Milk*** | Buffalo | Cow | Sheep |

| | | | |
|---|---|---|---|
| | Camel | Goat | |
| ***Other*** | Hides, buffalo, fresh | Skins, sheep, fresh | Hair, horse |
| | Hides, cattle, fresh | Wool, greasy | |
| | Skins, goat, fresh | Skins, sheep, with wool | |

*Note:* Meat includes indigenous meat sources (which include the meat equivalent of exported live animals and exclude the meat equivalent of imports); milk is whole, fresh milk products.
*Source: Livestock products included in FAO, FAOSTAT database.*

FAO data for crop and livestock production are scanty for small island nations, city states, and other small countries. The same gap-filling rules as for timber production are applied. Island economies and small states with missing data for all years are assumed to have zero crop and livestock production. Countries with crop and livestock production values equal to zero in the earliest year for which they *do* have data are also assumed to have zero production values in all earlier years.

As with timber production, crop and livestock production data for Belgium and Luxembourg prior to 2000 are grouped together and reported for "Belgium-Luxembourg." Production for these two countries is allocated according to their respective shares in total production for each particular crop or livestock product in 2000.

Finally, for many crop and livestock products, data may be missing for the most recent year (2018). In these cases, if data are available for 2017, then the same level of production is assumed for 2018.

## B. Unit prices for crop and livestock products

Unit prices are estimated for all crop and livestock products in terms of current US$ per ton. Prices are obtained from several FAO sources, each downloadable from the FAOSTAT database (Table 22).

*Table 22: Data sources for crop and livestock production*

| Element | Data sources and notes |
|---|---|
| **Prices for crop and livestock products** | • FAO, Value of Agricultural Production, Production, FAOSTAT database (link)<br>• FAO, Producer Prices – Annual, Prices, FAOSTAT database (link)<br>• FAO, Export Value, Crop and Livestock Products, Trade, FAOSTAT database (link)<br>• FAO, Export Quantity, Crop and Livestock Products, Trade, FAOSTAT database (link) |

Unit prices as reported in the FAO's estimates of the value of agricultural production are given priority, followed by the FAO estimates of producer prices. If country-specific data on prices are unavailable for a certain product, then regional or world averages are applied. Regional and world averages are weighted by production. Producer price data from FAO are available in units of standard local currency (SLC) as well as US dollars. Estimates of prices already converted into US dollars at market rates are used first; any missing values are filled by converting prices in SLC into US dollars using the World Bank DEC alternative exchange rate.

Data are missing from the FAO estimates of producer prices for the meat products listed in Table 23, so the prices for substitute products are assumed.

*Table 23: Meat products for which producer prices are not available, so prices for substitutes are used*

| Item | FAO item code | Substitute | Substitute item code |
|---|---|---|---|
| **Meat indigenous, ass** | 1122 | Meat, ass | 1108 |
| **Meat indigenous, buffalo** | 972 | Meat, buffalo | 947 |
| **Meat indigenous, camel** | 1137 | Meat, camel | 1127 |
| **Meat indigenous, cattle** | 944 | Meat, cattle | 867 |
| **Meat indigenous, goat** | 1032 | Meat, goat | 1017 |
| **Meat indigenous, horse** | 1120 | Meat, horse | 1097 |
| **Meat indigenous, mule** | 1124 | Meat, mule | 1111 |
| **Meat indigenous, sheep** | 1012 | Meat, sheep | 977 |
| **Meat indigenous, other camelids** | 1161 | Meat, other camelids | 1158 |

Export unit values are used in place of domestic prices only where data on producer prices and the value of agricultural production are missing. Export unit values are calculated by dividing total exports by the total export value. Because trade data are not available for "rice, paddy" (item 27) and "bastfibres, other" (item 782), trade data on "rice" (1946) and "jute + bast fibres" (1980) are used instead to estimate export unit values. Where country-specific trade data are missing, regional or world averages are applied instead.

Finally, there are some products for which pricing information—including export unit values—is entirely absent, although FAO does have data on production. These include those products listed in Table 24 below. For these products, prices or export unit values for similar products as shown in the table are assumed. For products with multiple substitutes, the average unit price (in US$/ton) of the substitutes is taken. Also, where country-specific estimates are lacking, regional or world averages are assumed.

*Table 24: Additional items missing pricing information for which prices for substitute products are used*

| Item | FAO item code | Substitute items | Substitute item codes |
|---|---|---|---|
| **Sugar crops, NES** | 161 | Average of sugar crops | 156, 157 |

| | | | |
|---|---|---|---|
| **Jojoba seed** | 277 | Oilseeds nes | 339 |
| **Tallowtree seed** | 305 | Oilseeds nes | 339 |
| **Hemp tow waste** | 777 | Fiber crops nes | 821 |
| **Coir** | 813 | Fiber crops nes | 821 |
| **Hides, cattle, fresh** | 919 | Hides, cattle, wet salted | 920 |
| **Hides, buffalo, fresh** | 957 | Hides, buffalo, dry salted<br>Hides, buffalo, wet salted | 959<br>958 |
| **Skins, sheep, fresh** | 995 | Skins, sheep, dry salted<br>Skins, sheep, wet salted | 997<br>996 |
| **Skins, goat, fresh** | 1025 | Skins, goat, wet salted | 1026 |
| **Hair, horse** | 1100 | Hair, fine<br>Wool, hair waste<br>Hair, goat, coarse | 1218<br>1009<br>1031 |

Note: NES: Not elsewhere specified

Table 25 and Table 26 provide a count of observations for which the different data sources are used to estimate crop and livestock prices. Each observation represents a particular crop and country. As shown in the tables, FAO's estimates of the value of agricultural production are the main data source for both crops and livestock products. Data on producer prices and the value of agricultural production for crops are thin prior to 1991. FAO's trade data are used more for pricing livestock products than for crops.

*Table 25: Crop price data sources (number of observations per year)*

| Crop price data source | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2018 |
|---|---|---|---|---|---|---|---|
| **FAO, export unit value** | 3,551 | 1 | 1 | 1 | 1 | 1 | |
| **FAO, export unit value, regional average** | 1,260 | | | | | | |
| **FAO, export unit value, world average** | 140 | | | | | | |
| **FAO, producer price** | | 86 | 161 | 180 | 142 | 106 | 48 |
| **FAO, producer price, old data** | | 3 | 5 | | | | |
| **FAO, producer price, regional average** | | 33 | 47 | 48 | 41 | 31 | 3 |
| **FAO, producer price, substitute** | | | | | | 1 | |
| **FAO, producer price, world average** | 28 | 4 | 5 | | 1 | | |
| **FAO, unit value** | | 4,952 | 5,418 | 5,477 | 5,646 | 5,779 | 5,806 |
| **FAO, unit value, regional average** | | 2,350 | 2,208 | 2,244 | 2,275 | 2,249 | 2,282 |
| **FAO, unit value, world average** | 1,059 | 317 | 165 | 177 | 188 | 180 | 183 |
| **WB staff, producer price, interpolated** | | | 1 | 4 | 5 | 3 | |
| **WB staff, producer price, removed outlier** | | | 1 | 4 | 4 | 4 | 4 |
| **WB staff, unit value, interpolated** | | 37 | 16 | 20 | 36 | 1 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **WB staff, unit value, removed outlier** | | 546 | 598 | 677 | 675 | 739 | 778 |
| **WB staff, unit value, substitute** | | 1 | 1 | 3 | 2 | 1 | 2 |
| **WB, producer price, extrapolated** | | | | | | | 1 |

*Note: Each observation represents a country and crop for which price data are available; blanks indicate zero observations; "unit value of production" data are from FAO's Value of Agricultural Production data series; "producer price" data are from FAO's Producer Price database; "export unit values" are from FAO's trade database.*

*Table 26: Livestock product price data sources (number of observations per year)*

| Crop price data source | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2018 |
|---|---|---|---|---|---|---|---|
| **FAO, export unit value** | 308 | 280 | 311 | 269 | 253 | 211 | |
| **FAO, export unit value, regional average** | 295 | 272 | 256 | 234 | 194 | 155 | |
| **FAO, export unit value, world average** | 48 | 48 | 37 | 26 | 88 | 5 | |
| **FAO, producer price** | | 29 | 58 | 268 | 251 | 219 | 104 |
| **FAO, producer price, old data** | | 2 | 1 | | | | |
| **FAO, producer price, regional average** | | 6 | 27 | 333 | 365 | 389 | 402 |
| **FAO, producer price, world average** | | | 2 | 30 | 19 | 45 | 122 |
| **FAO, unit value** | | 537 | 575 | 375 | 385 | 388 | 383 |
| **FAO, unit value, regional average** | | 498 | 458 | 131 | 136 | 139 | 142 |
| **FAO, unit value, world average** | 158 | 70 | 43 | 7 | 8 | 8 | 8 |
| **WB staff, producer price, interpolated** | | 1 | 1 | 35 | 21 | 8 | |
| **WB staff, producer price, removed outlier** | | 2 | 7 | 17 | 27 | 18 | 13 |
| **WB staff, unit value, interpolated** | | 8 | 3 | 3 | 2 | | |
| **WB staff, unit value, removed outlier** | | 69 | 55 | 46 | 43 | 50 | 49 |
| **WB, producer price, extrapolated** | | | | | | | 41 |

*Note:* Each observation represents a country and crop for which price data are available; blanks indicate zero observations; "unit value of production" data are from FAO's Value of Agricultural Production data series; "producer price" data are from FAO's Producer Price database; "export unit values" are from FAO's trade database.

## C. Rental rates and rents for crop and livestock products

Rents are estimated for crops as:

(4.15) $$R_{c,k,t} = q_{c,k,t} * p_{c,k,t} * a_g$$

where $R_{c,k,t}$ represents rents in country *c* from crop *k* harvested in year *t*; $q_{c,k,t}$ denotes production for that individual country, crop, and year; $p_{c,k,t}$ denotes the unit price; and $a_g$ is the average rental rate assumed for all countries and crops grown in region *g*. The rental rate *a* is equal to the ratio of (price – cost) / price. The rental rate is not given a *t* subscript because it is assumed to be constant over time. Estimates of rental rates are provided by Evenson and Fuglie (2010) and reported in Table 27.

Rents from livestock products are differently for livestock raised in extensive versus intensive production systems. Intensive systems are characterized by high output of animal products per unit surface area, and extensive systems use land areas of low production and under conditions of moderate grazing. Livestock rents are calculated as:

(4.16) $$R_{c,k,t} = (q_{c,k,t} * p_{c,k,t} * 2a_g)e_c + (q_{c,k,t} * p_{c,k,t} * a_g)(1 - e_c)$$

where *R*, *q*, *p*, and *a* are as defined above for crops; $e_c$ is the share of livestock production in extensive systems for livestock products in country *c*; and $(1 - e_c)$ is the share of livestock production in intensive systems. For livestock raised in extensive production systems, the rental rate is assumed to be twice that for intensive systems[18]. The same rental rates assumed for crop products are assumed for livestock products in intensive systems (Table 27).

*Table 27: Average rental rates assumed for crops and livestock products by region*

| Region | Crops | Livestock (intensive) | Livestock (extensive) |
|---|---|---|---|
| **Sub-Saharan Africa, developing** | 0.23 | 0.23 | 0.46 |
| **Sub-Saharan Africa, developed** | 0.22 | 0.22 | 0.44 |
| **South Asia** | 0.23 | 0.23 | 0.46 |
| **Southeast Asia** | 0.25 | 0.25 | 0.50 |
| **Oceania, developing** | 0.25 | 0.25 | 0.50 |
| **Oceania, developed** | 0.19 | 0.19 | 0.38 |
| **Northeast Asia, developing** | 0.22 | 0.22 | 0.44 |
| **Northeast Asia, developed** | 0.23 | 0.23 | 0.46 |
| **Latin America and Caribbean** | 0.22 | 0.22 | 0.44 |
| **Middle East and North Africa** | 0.22 | 0.22 | 0.44 |
| **Western Europe** | 0.17 | 0.17 | 0.34 |
| **Eastern Europe** | 0.17 | 0.17 | 0.34 |
| **Former USSR countries** | 0.19 | 0.19 | 0.38 |
| **North America** | 0.19 | 0.19 | 0.38 |
| **All countries** | **0.21** | **0.21** | **0.42** |

The share of livestock produced in extensive versus intensive systems is apportioned according to the percent of ruminant meat produced in grazing systems, as estimated by the FAO for its Global Livestock

[18] As recommended by Pierre Gerber, Senior Livestock Specialist, World Bank, April 2016.

Environmental Assessment Model[19]. FAO estimates the percent of meat produced in grazing systems for 228 countries and other administrative regions. Where country-level estimates of meat production in grazing systems by the FAO are not available, regional averages of *e* are applied (weighted by the total area of pasture). Economies for which regional averages of *e* are used include:

- Bermuda
- Cabo Verde
- Gibraltar
- Greenland
- Monaco
- Mauritius
- French Polynesia
- Tonga
- Taiwan, China
- Samoa

Once rents are estimated for each crop and livestock product *k* produced by country *c* in year *t*, total rents from agricultural land are estimated by summing rents for all products *k*.

[19] See FAO, Global Livestock Environmental Assessment Model (GLEAM), http://www.fao.org/gleam/en/.

# V. Protected Areas

Areas protected for conservation and preservation of ecosystems provide a range of services to the country. For instance, wildlife reserves can generate significant revenues for developing countries in particular from international tourism activities. And about one-third of the world's big cities get their drinking water from sources in or downstream of protected areas, saving billions of dollars in supply and treatment costs thanks to forests and wetlands that regulate the flow of water and remove contaminants (Dudley et al 2010). Valuing such ecosystem services on a global basis, however, is difficult. For this reason, protected areas are valued in the World Bank wealth accounts using a simplified approach. Under this approach, the quasi-opportunity cost of protection per unit area of land contained in terrestrial protected areas is estimated as the lower of returns to cropland and pastureland. This is likely to be a lower bound on the true value of protected areas. Returns are capitalized over a 100-year period as:

(5.1)
$$V_t = \sum_{i=1}^{i=100} \frac{\overline{R_t} * A_t}{(1+r)^i}$$

where $V_t$ is the value of protected areas in year $t$; $\overline{R_t}$ is the minimum of total rents per square kilometer (sq km) of cropland and total rents per sq km of pastureland, averaged over a five-year period from year $t$ to year $t$-4; and $A_t$ is the area of land under protection in year $t$.

## A. Area of cropland, pastureland, and protected areas

Data sources for the area of cropland, pastureland, and protected areas are listed in Table 28.

*Table 28: Data sources for crop and livestock production*

| Element | Data sources and notes |
|---|---|
| **Area of cropland and pastureland** | • World Bank, "Land area (sq km)" (AG.LND.TOTL.K2), World development Indicators (WDI) database (link)<br>• World Bank, "Agricultural land (% of land area)" (AG.LND.AGRI.ZS), WDI database (link)<br>• World Bank, "Arable land (% of land area)" (AG.LND.ARBL.ZS), WDI database (link)<br>• World Bank, "Permanent cropland (% of land area)" (AG.LND.CROP.ZS), WDI database (link) |
| **Terrestrial protected area** | • World Bank, "Terrestrial protected areas (% of land area)" (ER.LND.PTLD.ZS), WDI database (link)<br>• World Bank, "Land area" (AG.LND.TOTL.K2), WDI database (link) |

Data on the area of terrestrial protected areas are obtained from the World Bank's WDI database. Protected areas include all nationally-designated protected areas of at least 1,000 hectares with a recorded location and extent in the World Database on Protected Areas (WDPA), compiled and maintained by the UN Environmental Programme's World Conservation Monitoring Centre (UNEP-WCMC) and the International Union for Conservation of Nature (IUCN). A protected area is defined by IUCN as "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley 2008). The IUCN groups protected areas into six categories: (I) strict nature reserve and wilderness area, (II) national park, (III) natural monument or feature, (IV) habitat/species management area, (V) protected landscape, (VI) protected area with sustainable use of natural resources. Data on protected areas in the WDPA and WDI are provided for 1990, 2000, and 2014. Values for in-between years are interpolated linearly. Countries without data are assumed to have zero nationally-designated protected areas.

Data on the area of agricultural land are obtained from the WDI database. The data in the WDI are sourced from the FAO. Agricultural land is defined as the sum of arable land, permanent cropland, and permanent pasture. Arable land is land under temporary crops, temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Permanent cropland consists of land cultivated with crops that are not replanted after each harvest (e.g., cocoa, coffee, and rubber); permanent cropland excludes land under trees grown for wood or timber. Permanent pasture is land that is used for five or more years for forage, including natural and cultivated crops. Using the WDI data, the total area of cropland is calculated as the sum of arable land and permanent cropland. Permanent pasture is calculated as a residual – the difference of agricultural land, arable land, and permanent cropland.

As with the data on crops, livestock, and forestry, the FAO data on the area of agricultural land is spotty for island economies, city states, and other small countries. Missing values for total land area and the area of agricultural land are gap-filled according to the following rules. First, as long as population data are available for a country in the WDI, if data on total land area are missing, then total land area is gap-filled by simply assuming that the area is unchanged from the years with data. Missing values for the area of cropland, pastureland, and total agricultural land are gap-filled by regressing and extrapolating time trends for the percent of total land area represented by each land use. To do this gap-filling, a country must have at least 10 years of data on each type of land use. In extrapolating time trends, the area of cropland and pastureland is restricted such that it cannot exceed total agricultural land. Internal gaps in data on the area of cropland and pastureland are filled linearly. Data on the area of cropland, pastureland, and total land area are only filled for those years with at least some data from FAO on crop or livestock production for a country. Countries for which the area of cropland and pastureland are gap-filled by regressing time trends and extrapolating. The gap-filling mostly affects countries in the years before 1995. Additionally, there are countries for which FAO has estimates of total agricultural land, but not of the breakdown for arable land, permanent cropland, and thus pastureland. For these countries, it is assumed that share of cropland and pastureland in total agricultural land is proportional to the share of crops and livestock products in total agricultural revenues. If data on total agricultural revenues are lacking, it is simply assumed that cropland and pastureland each represent 50 percent of total agricultural land. Countries for which missing data on the area of cropland and pastureland are gap-filled in this way Finally, we capped outlier values for Belize, Central African Republic, Nepal, Lao PDR, and Suriname.

## B. Value per hectare of protected areas

Unit values for returns per sq km of cropland and pasture are truncated by excluding outliers above the following threshold: median value per sq km + 1.5 * (third quartile – first quartile). If returns per sq km of cropland or pastureland in a country exceed this threshold, then the median value from the sample of all countries is used instead. The world median value is also assumed for countries that are missing data on returns per sq km of cropland or pastureland but do have data on the area of land contained in designated protected areas.

# VI. Mangroves

The asset value of mangroves is explicitly included in the World Bank's core wealth accounts for the first time in this wealth edition. As a type of forest, partial mangrove asset values are implicitly included in the forest asset accounts already. However, forest asset value is based only on value for timber, nontimber forest products, watershed services, and recreation services. Mangroves also provide a critical ecosystem service that is not currently included: protection from coastal flooding.[20]

The value of mangroves for coastal flood protection was estimated in several steps, which are further elaborated in Beck et al. (2021). First, a combined set of process-based storm and hydrodynamic models are applied to identify the area and depth of flooding using model scenarios with and without reefs and mangroves for five storm frequency events, 1 in 5, 10, 25, 50, and 100 years driven by local storm data.

These flood extent and depth data are then overlaid on historical data on populations and the value of CWON produced capital assets, downscaled to 90 by 90 meters to identify a probabilistic distribution of flood damages (risk) and avoided damages (habitat benefits). All models were run for three years with data on the historical distribution of mangroves (1996, 2010, 2015), aggregated to the national level, then extrapolated and/or interpolated to provide annual values for 1995 to 2018.

### *Estimating flood risk, flood protection benefits and the asset value of mangroves*

The flood protection benefits provided by mangroves are assessed as the flood damages avoided to people and property by keeping mangroves in place. Beck et al. 2021 coupled offshore storm models with coastal process and flood models to measure the flooding that occurs: (i) with and without mangroves (ii) under cyclonic and non-cyclonic storm conditions (iii) by storm frequency (return period), across the globe. These flood extents and depths are used to estimate the annual expected flood damages to people and property and hence the expected benefits of mangroves in social (people protected) and economic terms (value of property protected). Estimates are based on a set of global statistical models, hydrodynamic process-based models and socioeconomic data. All these processes are grouped into 5 steps following the Averted Damages (Expected Damage Function) approach, commonly used in engineering and insurance sectors and recommended for the assessment of coastal protection services from habitats. Many aspects of these models such as connections between wind, waves, run-up and flooding have been extensively validated.

The Averted Damages approach provides a rigorous foundation for estimates of flood risk and habitat benefits (Beck et al. 2021). This approach is (a) quantitative in contrast to other approaches that use indicator (expert) scores to assess shoreline vulnerability, (b) it uses process-based models and statistical tools to assess hydrodynamics, (c) it uses the methods and tools of risk agencies, insurers and engineers, (d) it is consistent with approaches for national accounting, and (e) it accurately captures impacts of extreme events.

[20] Mangroves also provide protection from coastal erosion, but that value is not yet included.

Flood models were used to generate a dataset of several thousand simulations to describe the physical relationships between tropical cyclones, offshore wave climate, mangrove extent and geometry and extreme water levels (i.e., flood height) along the shoreline for five storm frequency events (1 in 5, 10, 25, 50, 100-yr) driven by local storm data. This dataset is then used to estimate how mangroves modify extreme water levels for every kilometer of mangrove shoreline globally. Global flood depths and extents are then estimated by intersecting the global extreme water levels with 90-meter SRTM-DTM (Shuttle Radar Topography Mission). Finally, the resulting maps of flood depths and extents on socioeconomic asset information downscaled to 90 x 90 meters. Flooded socioeconomic assets are then assessed by flood depth to identify flood damages (risk) and avoided damages (mangrove benefits).

To estimate coastal damage and risk and a multi-step approach is implemented:

### Step 1. Global Population and Stock Distribution

The distribution and density of population is obtained from the spatial raster GHS-POP. This dataset contains global residential population estimates at 250 m resolution for 1975, 1990, 2000 and 2015. These global population rasters provided by CIESIN GPWv4.10 were disaggregated from census or administrative units to 250 m grid cells, and informed by the distribution and density of built-up as mapped in the Global Human Settlement Layer (GHSL) global layer per corresponding epoch. Beck et al. (2021) used the four years (1975, 1990, 2000, and 2015) to adjust 1996 and 2010 scenarios, which are the target years of this analysis. Global grid population from 1996 was adjusted by interpolation of 1990 and 2000 population distribution. Global grid population from 2010 was adjusted by interpolation of 2000 and 2015 population distribution. Then they calibrate both, 1996 and 2010 interpolated grids, with nationwide population statistics from the World Bank (World Bank Data) The calibration consists of adjusting the total people per country from the interpolated grids to the World Bank data. Global stock is calculated using Penn World Table, version 9.1 (PWT 9.1). This version is a database with information on relative levels of income, output, input and productivity. The table includes 182 countries and 68 years, between 1950 and 2017.

For the analyses of global stocks Beck et al. (2021) used the national data of Capital Stock at constant 2018 national prices. Then, they calculate the stock per capita at each country and multiply these national values by the population located at each grid cell. A global stock distribution raster at 250 meters resolution is generated.

### Step 2. Resampling Population and Stock Grids to Flood Maps Resolution (90m)

To overlay flood and assets maps, both must be at the same horizontal resolution. Beck et al. (2021) downscaled socioeconomic data rather than upscaling flood grids. Global population and stock rasters at 250 meters are resampled to the same horizontal resolution as the flood maps (90 m). They used ArcGIS toolbox to carry on the spatial redistribution of population and stock grids, and then calibrate the new rescaled rasters, by adjusting the total population and total stock per country at 90 m resolution to those at 250 m.

### Step 3. Exposure: People and Stock in Flooded Areas

Here the number of people and the stock exposed to coastal flooding in 1996, 2010 and 2015 with and without mangroves is calculated. First the authors reclassify the flooding raster into 1 and 0 values. Then they multiply population and stock rasters by the reclassified flood raster and obtain the global distribution of people and stock exposed to coastal flooding. The exposure layers will inform how many people and assets are in flooding areas, but not the real damage to people and the real economic loss (Risk). Calculating flood risk requires that flood damages are estimated using damage functions, that relate flood damages at a location to the flood depth at that location.

#### Step 4. Damage Coefficients

Flood damage depends on the water depth and the type of asset. Beck et al. (2021) use different damage functions for population and stock. For people they use a damage function that assumes that, in a grid cell, people are not affected by water below 30 cm in depth and all people are affected by flood water depths greater than 30 cm. This a commonly used threshold in civil protection services to decide when people must be evacuated.  For stock, Beck et al. (2021) combined data from JRC and Hazus depth damage curves to calculate global rasters of damage coefficients to people and stock.

#### Step 5. Risk- People and Stock Damaged by Coastal Flooding

To calculate risk, Beck et al. (2021) multiply damage coefficient rasters by global population and stock distribution layers create 120 risk maps for the different conditions and scenarios.

#### Step 6. Nationwide Aggregation Results

Risk to people and stock is aggregated at national scale. The authors first create a 10 km external buffer at each country and find the pixels that lay into each country buffer boundary. They calculate the total number of people and the total stock value on each country under each scenario.

#### Step 7. Annual Expected Risk and Benefits

In addition to assessing risk for specific events (e.g., 100-year storm event), Beck et al. (2021) also examined average annual expected damages and benefits provided by mangroves. To estimate annual risk, they integrated the values under the extreme value distribution curves that compare stock damaged or people affected, by storm return period, i.e., the integration of the expected damage with the probability of the storm events.

#### Step 8. 100-Year Asset Value Calculation

Beck et al. (2021) calculated the Present Value of mangrove benefits over a period of 100 years. They assumed a constant benefit flow and 4% discount rate to obtain the 100-year asset value (Equation (6.1)).

(6.1) $$PV = \sum_{i=1}^{i=100} \frac{AEB}{(1+r)^i}$$

where *PV* is the Present Value, *AEB* are the Annual Expected Benefits, *r* is the discount rate (4%) and "*i*" is each year within the life cycle period (i=1-100 years).

Table 29 presents some key data sources.

*Table 29: Data Sources for Mangroves Wealth Estimation*

| Indicator | Data sources and notes |
|---|---|
| **Total mangrove area** | • Global Mangrove Watch Database, www.globalmangrovewatch.org |
| **Coastal assets at risk** | • Coastal population: Global Human Settlement Layer (GHS-POP GRID) dataset, from the European Commission, https://ghsl.jrc.ec.europa.eu/ghs_pop2019.php<br>• Coastal produced capital: Penn World Table version 9.1 produced capital data, spatialized using coastal population, https://www.rug.nl/ggdc/productivity/pwt/). |
| **Annual service values per hectare** | • Modelled by Beck et al. 2021 |

### *Mangrove Data*

Global Mangrove Watch (GMW, Bunting *et al.*, 2018) (www.globalmangrovewatch.org/datasets), has just recently posted spatial mangrove distribution data for the following years: 1996, 2007, 2008, 2009, 2010, 2015, 2016. The GMW has generated a global baseline map of mangroves for 2010 using ALOS PALSAR and Landsat (optical) data, and changes from this baseline for seven epochs between 1996 and 2017 derived from JERS-1, ALOS and ALOS-2. Annual maps are planned from 2018 and onwards. The primary objective of the GMW has been to provide countries with mangrove extent and change maps, to help safeguard against further mangrove forest loss and degradation.

### *Population Data*

Global exposure data for people was obtained from GHS-POP GRID dataset, from the European Commission (https://ghsl.jrc.ec.europa.eu/ghs_pop2019.php). This new package provides estimates of global populations and their distribution for 1975, 1990, 2000 and 2015. The global distribution of population is at 250 m resolution. Residential population estimates for target years 1975, 1990, 2000 and 2015 provided by CIESIN GPWv4.10 were disaggregated from census or administrative units to grid cells, informed by the distribution and density of built-up as mapped in the Global Human Settlement Layer (GHSL) global layer per corresponding epoch.

*Capital Stock Data*

This study uses data from the Penn World Table version 9.1 from the Groningen Growth and Development Center (https://www.rug.nl/ggdc/productivity/pwt/). This version is a database with information on relative levels of income, output, input and productivity. The table covers 182 countries and 68 years, between 1950 and 2017. Beck et al. (2021) particularly used the nationwide data of Capital Stock at constant 2011 national prices and transformed into constant 2018 national prices. Then, they calculate the stock per capita at each country and multiply these national values by the population located at each grid cell. They finally obtain the global stock distribution at 250 meters resolution. There were 22 tropical nations that had mangroves but were not included in the Penn World Table; Beck et al. (2021) filled most of these gaps with national data from the World Bank. There were a few remaining countries and territories that was not possible in the analyses due to the lack of economic data, including are Eritrea, French Guiana, New Caledonia, Micronesia, Palau, Somalia, Guadelupe, Martinique, Timor Leste, Mayotte, Samoa, Netherlands Antilles, US Virgin Islands, Saint Martin and American Samoa.

*Gross Domestic Product*

World Development Indicators from the World Bank (https://datacatalog.worldbank.org/dataset/world-development-indicators) were used to obtain GDP data for each country involved in this study. GDP information is available from 1960 to 2020.

# VII. Fisheries

The asset value of marine fisheries is included in the World Bank's core wealth accounts for the first time in this wealth edition. Fisheries wealth is calculated as the discounted value of the stream of rents expected over the lifetime of the asset. Landed value is based on estimates of the Sea Around Us (SAU) project, which is more comprehensive and detailed than the United Nations Food and Agriculture Organization's (FAO's) fisheries data. SAU also has calculated fishing costs and subsidies, which are used to estimate financial and economic rent.

For the core wealth accounts, the lifetime of fisheries stock is set to 100 years, as for other renewable natural capital. Indicators of fish management status are estimated and will be incorporated in future work to reassess assumptions about the lifetime of fish stock. The impact of two scenarios about climate change on fish abundance, spatial distribution and maximum catch potential (MCP), are estimated using an integrated assessment model developed for the Intergovernmental Panel on Climate Change. The estimated MCP is linked to a bioeconomic model to assess the impact on landed value, rents, and asset value.

*Fisheries data*

The calculation of fisheries wealth requires data on marine fisheries production (catch), ex-vessel price of each exploited species, and fishing costs.

*Catch data*

Lam and Sumaila (2021) obtained catch data from two different sources including Food and Agriculture Organisation of the United Nations (FAO) and the *Sea Around Us* (SAU) reconstruction database (www.seaaroundus.org). Marine capture production data (tonnes) of each country and species from 1991 to 2018 were obtained from the latest version of FishStatJ (2020) of the FAO's Fisheries and Aquaculture statistics[21].

Since the reconstructing catch data provided by the SAU database utilized a wide variety of data sources and information to estimate all of the fisheries components such as subsistence catch, recreational catch and discards that are missing from the official reported data, Lam and Sumaila (2021) included this set of data in our analysis to capture a more comprehensive estimation of the total asset values of marine fisheries. Annual catch data were extracted from the *Sea Around Us* database of reconstructed catches, which cover the years 1991 to 2016, distributed onto 180,000, 30' latitude x 30' longitude spatial cells of the world ocean.

The catch allocation process by the SAU produced spatial time series of landings data from 1991 to 2016 that were aggregated into different fishing entities, and which distinguished between landings by different

[21] FAO's Fisheries and Aquaculture statistics (http://www.fao.org/fishery/statistics/software/fishstatj/en).

taxa, different fishing gear types, between distant-water and domestic fleets, different catch types (landings and discards) and between different fishing sectors (including industrial, subsistence, artisanal and recreational). Lam and Sumaila (2021) included 203 fishing entities in this study and 31 countries are excluded from this analysis as these are small island countries and have not been included in the World Bank list of economies. There are 2,741 taxa at different taxon levels (species, genus, family, order, class and ISSCAAP levels) being included in the database and in this study. Each of the taxon is associated to a functional group which plays a specific functional role in the ecosystem, and there are 31 functional groups in the databases. Hence, the catch data is also arranged by each functional group.

The catch reported to FAO from its members countries is lower than the reconstructed catch (FAO, 2016). The small-scale fishery sectors, i.e. artisanal, subsistence and recreational received little attention in data collection systems, so their catches are underrepresented in, or absent from, official catch statistics, as are discards and illegally caught fish. Thus, the total reconstructed catch from 1991 to 2016 was around 1.5 – 1.8 times of the total reported catch in Europe and East Asia, which is comparable to the ratio of global reconstructed to the reported catch (i.e. about 1.5 times). The "catch reconstruction" approach utilized a wide variety of data and information sources to estimate the catch of those sectors that are missing from the official reported data. Globally, the reconstructed catch tends to decrease in the recent decade but reported catch remain more or less stable in this decade. In the East Asia and Pacific region, the reported catch still tends to be stable in the recent 10 years, but this is mainly due to the over-reporting by a few countries.

Lam and Sumaila (2021) extended the catch series for the present study based on FAO catches in 2017 and 2018. This was first performed (*i*) by comparing the complete list of fishing countries in the *Sea Around Us* catch database with a list of all countries occurring in the FAO data in 2017 and 2018. Then, (*ii*) the authors calculated the proportions of catch of each fishing country in the *Sea Around Us* catch database to that reported by FAO in 2016. Finally, (*iii*) they used these proportions and the FAO production data in 2017 and 2018 to estimate the reconstructed catch of each fishing country in these two years, assuming that these proportions did not change much since 2016. The results are catch by each fishing country in 2017 and 2018.

### *Landed values and price data*

Ex-vessel prices are the prices that fishers receive directly for their catch, or the price at which the catch is sold when it first enters the supply chain. Sumaila et al. (2007) first established a global ex-vessel fish price database to understand the economic behavior of the world fisheries and address the issue of lacking information for sustainably management of marine resources. The first version of the fish price database provided the ex-vessel prices for each exploited marine taxon, by each fishing country for each year from 1950 to 2006 and it is capable of combining to each recorded catch data in the earlier version of the SAU catch database. The fish price database was constructed by collecting and compiling scattered data from secondary data sources and working with the international partners. A rule-based approach was adopted to estimate missing prices data, using a combination of various rules across taxa, countries and years. Also, a system of penalties was used as a measure of uncertainty of each of the data point.

This price database is a living database with continuous updates on both the input data and the price estimation methods. The most up-to-date database has fish price data from 1950 to 2010 for marine taxa that are destined for both direct and non-direct human consumption. By combining the catch data with the fishing ex-vessel price data of each marine taxon, the landed values can be estimated for different fishing country at different spatial locations. For example, the total landed values in each grid cell in a particular year is calculated by:

$$LV_{yr} = \sum_{i}^{i=m}(\sum_{j}^{j=n}(C_{i,j,yr} * P_{i,j,yr})) \quad (7.1)$$

where $LV_{yr}$ is the total landed values in a particular grid cell in a particular year (*yr*), *i* is the fishing country, *m* is the number of countries fishing in this grid cell, *j* is the exploited marine taxon, *n* is the number of marine taxa caught by each fishing country in that grid cell in year *yr*, $C_{i,j,yr}$ is the annual total catch of a taxon (*i*) caught by country *j* in year *yr* and $P_{i,j,yr}$ is the unit ex-vessel price data of this particular taxon (*i*) by fishing country (*j*) in year *yr*.

Since the last round of the update of the price data was only up to year 2010, Lam and Sumaila (2021) extended the ex-vessel price data from 2011 to 2018. Here assuming the ex-vessel prices of each taxon by each country remind unchanged after 2011. Lam and Sumaila (2021) carried forward the price data of each taxon by each fishing entity in 2010 or the latest year to the data gaps from 2011 to 2018.

Lam and Sumaila (2021) used the information on World Bank price deflators to convert the 2010 USD price to 2018 real US dollars.

### *Fishing cost*

Lam and Sumaila (2021) updated the global fishing cost database from Fisheries Economic Research Unit (FERU) at the UBC to cover the years from 1991 to 2018, and to further distinguish costs of small-scale, large-scale and distant water fleets. Small scale fleet includes all vessels under 12m or 15 GT using static gears (drift and/or fixed netters, vessels using pots and/or traps, vessels using hooks, vessels using passive gears only for vessels). Large scale fleet segment includes all vessels using towed gears (dredgers, demersal trawlers and/or demersal seiners, vessel using other active gears, vessels using polyvalent active gears only, purse seiners, beam trawlers, pelagic trawlers) and vessels over 12m or 15GT using static gears operating within the EEZ of the flag state. The long-distance fleet includes vessels over 24m or 100GT operating in other countries fishing regions or beyond the EEZ of the flag state. The fishing cost data in this database is arranged by year, fishing entity, super gear type and fishing sectors. Gear types included in the database were based on the gear categorization system of the Sea Around Us project (http://www.seaaroundus.org/) (Table 2). The fishing sectors are segregated into Industrial, subsistence, artisanal and recreational fishing sectors.

Lam and Sumaila (2021) collected secondary data for vessels operating in major fisheries and in major fishing nations in each of the seven World Bank regions of the world: (1) Sub-Saharan Africa; (2) East Asia and Pacific; (3) Europe and Central Asia; (4) North America; (5) Middle East and North America; (6) Latin

America and Caribbean; and (7) South Asia. The first step was to identify the sources of fishing cost data, mainly secondary sources, i.e. websites and grey literature, such as government, FAO, and consultant reports (see Lam and Sumaila 2021 for more details). The authors collected 4,300 data points with fishing cost data from various sources. These data are reported in 56 countries in the seven regions. The observed data is biased towards the high-income group and the number of data in this group represents about 89% of the total number of observed data. Fishing cost data in the other three income groups are under-represented.

*Fishing Subsidies*

Capacity-enhancing subsidies and population expansion by the countries adjacent and/or exploiting the fisheries resources within various EEZs will put further pressure on the marine resources in these EEZs. Capacity-enhancing subsidies contribute to half of the total fisheries subsidies in all countries; this category of subsidies enhance overcapacity and overfishing by increasing profits. Capacity-enhancing subsidies *(‘*disinvestment’ programs in fish stocks*)* include:

- Tax exemption programs;
- Fuel subsidies;
- Foreign fishing access payments;
- Boat construction renewal and modernization programs;
- Fishing port construction and renovation programs;
- Fishery development projects and support services;
- Marketing support, and storage infrastructure programs.

There are other two types of subsides including beneficial and ambiguous subsidies. Beneficial subsidies can be considered as ‘investment’ programs in fish stocks and they include:

- Fisheries management and services;
- Programs for marine protected areas for sustainable fisheries;
- Fisheries research and development.

Ambiguous subsidies can be considered as programs may benefit or harm fish stocks and here are some examples:

- Fisher assistance packages;
- Vessel buyback programs;
- Rural fishers’ community development programs.

Lam and Sumaila focused only on three major subsidies including fuel subsidies, foreign fishing access payments and tax exemption programs.

The original fishing subsidy data are obtained from various sources including Organization for Economic Cooperation and Development (OECD), FAO, Asia-Pacific Economic Cooperation (APEC), published reports and literatures. In the original dataset, the authors collected the subsidy data of 165 maritime countries with 30 types of subsidies from 1989 to 2019. There are about 4,300 subsidy data points and these data points are biased towards the countries in the high-income group. Two types of subsidy, i.e., monitoring control and surveillance programs and development grants for fishery projects have relatively more points than other subsidy types.

The previous versions of the global fishing subsidy table developed by the Fisheries Economic Research Unit, FERU (Sumaila *et al.*, 2010, 2019a, 2019b), standardized the data to one year. Here, the authors extend the database to include the time series data. Four gap filling approaches are applied here depending on the subsidy types and these approaches include a general approach for filling gaps for all subsidy types, except fuel subsidies, fishing access agreements and marine protected areas (MPAs), for which customized approaches were used (more details provided in Lam and Sumaila 2021).

The data sources for each indicator are included in Table 30. For the detailed methodology for calculating fisheries wealth, please refer to Chapter 6 in this report, *Blue Natural Capital: Mangroves and Fisheries*, and supporting technical documents by Lam and Sumaila (2021).

*Table 30: Data Sources for Fisheries*

| Indicator | Data sources and notes |
|---|---|
| **Catch** | • Sea Around Us database, www.seaaroundus.org<br>Data are collected on marine capture production (tonnes) of each country from 1991 to 2018 at species group level and spatialized. |
| **Ex-vessel price and landed values** | • Sea Around Us database, www.seaaroundus.org<br>Ex-vessel prices are the prices that fishers receive directly for their catch, or the price at which the catch is sold when it first enters the supply chain. |
| **Fishing costs and subsidies** | • Fisheries Economic Research Unit (FERU) at the UBC (Lam and Sumaila 2021) , updated to cover years 1991 to 2018 |
| **Fisheries management status** | • Fisheries Economic Research Unit (FERU) at the UBC (Lam and Sumaila (2021) , updated to cover years 1991 to 2018 |

### *Private Rents, Economic Rents and Wealth*

The following resource rent calculations are carried out using data provided in the previous steps:

i) ‘Private’ or *financial rent* estimates what accrues to the operators and does not take into accounts subsidies, which is a larger economic cost. It is calculated as

Financial Rent = Landed value – Fishing costs

Where Financial Rent $< 0$, operators cannot continue in the long term without subsidies

Where Financial Rent $> 0$, operators can fish profitably even without subsidies, but that does not mean they are not subsidized, which further increase private profitability

ii) *Economic rent* considers subsidies, by treating subsidies as a cost of production taken on by the government on behalf of the private operators

Economic Rent = Landed value – Fishing costs - Subsidies

Where Economic Rent + Subsidies $< 0$, fishing would not be financially profitable in the long term, may want to review either costs of fishing and/or subsidies

Where Economic Rent + Subsidies $> 0$, fishing is profitable to private operators

In CWON fisheries wealth estimation, private rents are used. Like other renewable assets the Present Value of fisheries wealth is estimated over a period of 100 years. A constant resource rent flow and 4% discount rate is assumed. The present value formula is:

(7.2)
$$PV = \sum_{i=1}^{i=100} \frac{PR}{(1+r)^i}$$

where *PV* is the Present Value, *PR* are the Annual Private Rents, *r* is the discount rate (4%) and “*i*” is each year within the life cycle period (i=1-100 years).

# VIII. Produced Capital

Produced capital consists of manufactured or built assets such as machinery, equipment, and physical structures. Estimates of produced capital stocks in the World Bank wealth accounts also include the value of built-up urban land, which is valued as a mark-up on other produced assets. This section first describes data sources and methods for estimating the value of machinery, equipment, and structures. It then explains the mark-up for urban land.

## A. Machinery, equipment, and structures

For the calculation of physical capital stocks, several estimation procedures can be considered. Some of them, such as the derivation of capital stocks from insurance values or accounting values or from direct surveys, entail enormous expenditures and face problems of limited availability and adequacy of data. Other estimation procedures, such as the accumulation methods and, in particular, the perpetual inventory method, are cheaper and more easily implemented since they require only investment data and information on the assets' service life and depreciation patterns. These methods derive capital series from the accumulation of investment series and are the most popular. The perpetual inventory method is, indeed, the method adopted by most OECD (Organisation for Economic Co-operation and Development) countries that estimate capital stocks (Bohm et al. 2002; Mas, Perez, and Uriel 2000; Ward 1976). This method is also used in the estimates of capital stock.

Table 31 lists the data sources for estimating investment and the stock of machinery, equipment, and structures.

*Table 31: Data sources for produced capital*

| Elements | Data sources and notes |
|---|---|
| **Produced capital stock** | • Feenstra, Inklaar, and Timmer (2015)<br>• Data available for download at http://www.ggdc.net/pwt |
| **Investment** | • World Bank, "Gross fixed capital formation (current USD)" (NE.GDI.FTOT.CD), World Development Indicators (WDI) database (link).<br>• World Bank, "GDP (current USD)" (NY.GDP.MKTP.CD), WDI database (link).<br>• World Bank, "Exports of goods and services (current USD)" (NE.EXP.GNFS.CD), WDI database (link).<br>• World Bank, "Imports of goods and services (current USD)" (NE.IMP.GNFS.CD), WDI database (link).<br>• World Bank, "Final consumption expenditure (current USD)" (NE.CON.TOTL.CD), WDI database (link). |

| | |
|---|---|
| | • World Bank, "Gross capital formation (current USD)" (NE.GDI.TOTL.CD), WDI database (link). |

For most countries, estimates of produced capital are obtained directly from the Penn World Table (PWT) 9.1 database. The PWT authors use the perpetual inventory method to estimate produce capital stocks for 182 countries from 1970 to 2017. For the World Bank wealth accounts, the PWT capital stock data are expressed in constant 2018 US$ at market exchange rates, using the PWT's asset-specific investment deflators to bring the data to real terms. The value for 2018 (not included in PWT 9.1) is estimated using 2018 investment data from the World Bank's WDI and depreciation rates from PWT 9.1.

The perpetual inventory method is implemented by grouping produced capital and investment into six general classes of assets (Table 32). Stock *K* of each asset *a* in country *i* and year *t* is:

(8.1)
$$K_{a,i,t} = K_{a,i,t-1}(1-\delta_a) + I_{a,i,t}$$

where $\delta_a$ is an asset-specific depreciation rate (assumed to be constant) and $I_a$ is investment. The total capital stock is the sum of $K_a$ for each of the six asset classes. Estimates of the total capital stock in PWT 9.1 are first converted to current US dollars at market prices, and then brought to constant US dollars using country-specific GDP deflators

In the PWT, capital stocks in year t = 0, the first year for which investment data are available for a country, are estimated by assuming an initial capital-output ratio, k, such that:

(8.2)
$$K_0 = Y_0 \cdot k$$

Initial capital-output ratios for all countries are set equal to the median capital-output ratio for all countries and years for which data are available. Initial capital-output ratios vary by asset type (Table 33Table 33: ), with initial stocks of information and communication technology (ICT) assets set to zero, given their short lifespans and small share in total assets.

*Table 32: Categories of manufactured assets in the Penn World Table, and assumed depreciation rates*

| Asset | Depreciation rate |
|---|---|
| **Residential structures** | 1.1% |
| **Non-Residential structures (other construction)** | 3.1% |
| **Transport equipment** | 18.9% |
| **Computers** | 31.5% |
| **Communication equipment** | 11.5% |
| **Software** | 31.5% |

| | |
|---|---|
| **Other machinery and assets** | 12.6% |

*Note:* Depreciation rates are based on rates used by the US Department of Labor, Bureau of Economic Analysis (Fraumeni 1997)
*Source: Feenstra, Inklaar, and Timmer (2015)*

*Table 33: Initial capital-output ratios*

| Asset | Capital/output ratio *k* |
|---|---|
| **Structures (residential and non-residential)** | 2.2 |
| **Transport equipment** | 0.1 |
| **Other machinery and assets** | 0.3 |
| **Total** | 2.6 |

*Source: Feenstra, Inklaar, and Timmer (2015)*

The primary sources of data for capital investment, *I*, by asset type are the:

- OECD national accounts;
- Economic Commission for Latin America and the Caribbean (ECLAC) national accounts; and
- EU KLEMS database.[22]

In the PWT 9.1, for any given year between 1970 and 2017, there are only 18-26 countries for which reported data are available from any of these sources for capital investment by asset type[23]. Capital investment for the remaining 141-149 countries in the PWT 8.0 is estimated using an alternative method. First, data on investment by asset type are taken from the International Comparison Program database of the World Bank. The ICP database covers 176 countries and provides investment data for the years 1970, 1973, 1975, 1980, 1985, 1993, 2005, 2011, and 2017. Trends in investment values for in-between years in the ICP data and for 2018 are gap-filled. They are assumed to mimic trends in indirect estimates of investment that are obtained by applying the commodity flow method (CFM), which assumes that investment in an asset varies with the economy-wide supply of that asset, where supply equals to output plus imports minus exports. In the case of structures such as buildings—which can neither be exported nor imported—investment is assumed to be equal to value added by the construction industry, as given

[22] http://www.rug.nl/research/ggdc/data/eu-klems-database

[23] Feenstra, Inklaar, and Timmer (2016) report that the availability of investment data in PWT 9.1 are much improved over earlier vintages of the PWT, with new data on investment in R&D. Details are still forthcoming. Here, the number of countries with investment data from the three sources for PWT 9.1 was estimated by downloading and comparing data from the three primary sources. Inklaar and Timmer (2013) only provide the total number of countries that are listed in these databases, so it is unclear for how many countries investment must be estimated using the CFM in any given year.

in the UN National Accounts, Main Aggregates database for most years[24]. For machinery and transport equipment, data on output are obtained from the UNIDO INDSTAT database. Figures for imports and exports are sourced from the UN Comtrade or Feenstra's World Trade Flows databases. Gaps within individual data series are interpolated linearly. Due to significant year-on-year variation in output and exports, smoothing techniques are then used to eliminate outliers.

In summing investment for each asset type, further adjustments are made to correct for exaggerated or unrealistic investment shares. For any given country and any given year, total investment in structures, machinery, and transport equipment is compared to data on gross fixed capital formation (GFCF)[25]. Investment in each of the asset types is re-scaled according to the ratio of computed investment to GFCF. For example, in 1991, investment computed for Azerbaijan using the CFM is 3.037 times reported GFCF, so investment in each asset type is divided by 3.037.

Investment in computers, communication equipment, software, and other machinery must be further disaggregated from total investment in machinery and equipment. This is done using data on investment in ICT from EU KLEMS, The Conference Board, and WITSA, though data are only available for "a subset of countries."

For countries without PWT estimates of the produced capital stock, the perpetual inventory method is used, but without disaggregating investment by asset type. Instead, a single depreciation rate of 5 percent is applied across all asset types, countries, and years. Also, a "one-hoss-shay" retirement pattern is assumed, so that the value of all assets fall to zero after year 20. In this way, the total capital stock *K* in year *t* is given by:

(8.3)
$$K_t = \sum_{i=0}^{19} I_i(1 - .05)$$

where *I* is total investment, converted to constant US dollars at market rates using country-specific GDP deflators. Total investment is approximated by gross capital formation. For the countries with incomplete series of gross capital formation data, investment series were estimated from data on output, final consumption expenditure (private and public), exports, and imports for the missing years. With this information, the investment series may be derived from the national accounting identity Y=C+I+G+(X-M) by subtracting net exports from gross domestic savings. In all cases, the ratios of the investment computed this way and the original investment in the years in which both series are available are very close to one. Still, to ensure comparability between both investment series, the investment estimates derived from the accounting identity were used only if the country-specific median of these ratios, for the period 1960–2018, was close to one (greater than 0.7 but less than 1.3). For the remaining countries still without

[24] For 1970, 1973, 1975, 1980, 1985, 1993, 2005, 2011, and 2017 data on investment in structures are taken from the International Comparison Program database of the World Bank.

[25] It is not clear what data sources are used for GFCF, although this is not a problem. Data on GFCF are consistently available for more than 200 countries in the UN National Accounts Main Aggregates database.

complete investment series, data on gross fixed capital formation are used for the missing years. For countries missing complete investment series, produced capital is estimated after adjusting the values obtained using a lifetime assumption of 14–19 years (as the case may be). The adjustment made is that values obtained using less than 20 years are multiplied with the median of the ratio of capital obtained from 20 years to that obtained from less than 20 years.

Former Soviet states and other newly formed countries present a particular challenge in constructing long-running investment series. Investment series for the post-Soviet states and other European countries missing data are estimated indirectly by extrapolating from trends in neighboring countries for which data are available. Proxy states with full investment series include Bulgaria, Turkey, and Hungary. For these three countries, total investment is summed for a base year (in constant US dollars) and then take the ratio of investment in the base year to investment for the three countries in other years to construct an index. This index is then used to extrapolate investment trends for the countries with missing data. In this end, this method of extrapolating investment by proxy is used to construct estimates of produced capital for only one economy with missing data, Kosovo (in 2014).

Finally, for countries missing data on produced capital stock and investment for only the most recent year or earliest year (2018 or 1995), the average growth rate of the produced capital stock in the 10 earlier years or 10 subsequent years is extrapolated to fill the missing value.

## B. Urban land

In the calculation of the value of a country's physical capital stock, the final physical capital estimates include the value of structures, machinery, and equipment, since the value of the stocks is derived (using the Perpetual Inventory Method) from gross capital formation data that account for these elements. In the investment figures, however, only land improvements are captured. Thus, the final capital estimates do not entirely reflect the value of urban land.

Drawing on Kunte et al. (1998), urban land is valued as a fixed proportion of the value of physical capital. Ideally, this proportion would be country-specific. In practice, detailed national balance sheet information with which to compute these ratios was not available. Thus, like Kunte et al. (1998), a constant proportion equal to 24 percent is assumed:

(8.4) $$U_t = 0.24K_t$$

where *U* is the value of urban land and *K* is the produced capital stock (machinery, equipment, and structures).

## IX. Net Foreign Assets

Net foreign assets (NFA) are a measure of the cross-border assets and liabilities held by a country's residents. A country's external asset position, or net foreign assets (*NFA*), is calculated as:

(9.1) $$NFA = FA - FL$$

where *FA* are total foreign assets and *FL* are total foreign liabilities. Total foreign assets are:

(9.2) $$FA = equity_a + FDI_a + debt_a + derivatives_a + forex$$

where $equity_a$ are portfolio equity assets; $FDI_a$ are foreign direct investment liabilities; $debt_a$ are debt assets; $derivatives_a$ are financial derivatives assets; and $forex_a$ are foreign exchange reserves (excluding gold). Similarly, total foreign liabilities are:

(9.3) $$FL = equity_l + FDI_l + debt_l + derivatives_l$$

where $equity_l$ are portfolio equity liabilities; $FDI_l$ are foreign direct investment liabilities; $debt_l$ are debt liabilities; and $derivatives_l$ are derivatives liabilities. Estimates of *NFA* are obtained from the updated and extended version of the External Wealth of Nations Mark II database developed by Lane and Milesi-Ferretti (2007) (Table 34). The Lane and Milesi-Ferretti database, last updated in early 2020, provides estimates of NFA for 1970-2019 for a total of 214 economies. Additional data sources and methods for extending the coverage of the Lane and Milesi-Ferretti database to additional countries and years are described Table 34 below.

*Table 34: Data sources for net foreign assets (NFA)*

| Elements | Data sources and notes |
|---|---|
| **NFA** | • Lane and Milesi-Ferretti (2007).<br>• Estimates of NFA for 1970-2019 for 214 economies from updated and extended Lane and Milesi-Ferretti database (link) |
| **Equity** | • International Monetary Fund (IMF). "Assets, Portfolio investment, Equity and investment fund shares, US Dollars." Balance of Payments and International Investment Position Statistics (BOP/IIP) database (link)<br>• IMF. "Liabilities, Portfolio investment, Equity and investment fund shares, US Dollars." BOP/IIP database (link).<br>• IMF. "Assets, Equity, BPM6, US Dollars." Coordinated Portfolio Investment Survey (CPIS) database (link). |

| | |
|---|---|
| | • IMF. "Liabilities, Equity, BPM6, US Dollars." CPIS database (link). |
| **FDI** | • IMF. "Assets, Direct investment, US Dollars." BOP/IIP database (link).<br><br>• IMF. "Liabilities, Direct investment, US Dollars." BOP/IIP database (link).<br><br>• UN Conference on Trade and Development (UNCTAD). "Foreign direct investment: Inward and outward flows and stock, annual, 1980-2014." UNCTADSTAT database (link). |
| **Debt** | • Bank for International Settlements (BIS). "Amounts outstanding/stocks, Total claims, All instruments, All currencies." Locational Banking Statistics (link).<br><br>• BIS. "Amounts outstanding/stocks, Total liabilities, All instruments, All currencies." Locational Banking Statistics (link).<br><br>• IMF. "Assets, Portfolio investment, Debt securities, US Dollars." BOP/IIP database (link).<br><br>• IMF. "Liabilities, Portfolio investment, Debt securities, US Dollars." BOP/IIP database (link).<br><br>• IMF. "Assets, Other investment, US Dollars." BOP/IIP database (link).<br><br>• IMF. "Liabilities, Other investment, US Dollars." BOP/IIP database (link).<br><br>• IMF. "Assets, Debt Securities, BPM6, US Dollars." CPIS database (link).<br><br>• IMF. "Liabilities, Debt Securities, BPM6, US Dollars." CPIS database (link).<br><br>• World Bank. "External debt stocks, total (DOD, current US$)" (DT.DOD.DECT.CD). International Debt Statistics database (link). |
| **Derivatives** | • IMF. "Assets, Financial derivatives (other than reserves) and employee stock options, Financial derivatives (other than reserves), US Dollars." BOP/IIP database (link).<br><br>• IMF. "Liabilities, Financial derivatives (other than reserves) and employee stock options, Financial derivatives (other than reserves), US Dollars." BOP/IIP database (link). |
| **Forex** | • IMF. "Total Reserves excluding Gold, Foreign Exchange, US dollars." International Financial Statistics (IFS) database (link).<br><br>• World Bank. "24_International reserves (excluding gold)."Joint External Debt Hub (link). |

Where estimates of *NFA* and its components are not available in the Lane and Milesi-Ferretti database, additional data are obtained from the following sources indicated in Table 34 above: (1) International Monetary Fund (IMF) Balance of Payments and International Investment Position (BOP/IIP) database; (2) IMF Coordinated Portfolio Investment Survey database; (3) UN Conference on Trade and Development (UNCTAD) UNCTADSTAT database; (4) World Bank Joint External Debt Hub; (5) World Bank International Debt Statistics; and (6) Bank for International Settlements (BIS) Locational Banking Statistics. Note that in (1), the IMF BOP/IIP database, debt assets and liabilities are the sum of debt securities and other investment. In (6), the BIS data, "total liabilities" are external debt liabilities of counterparties *owed to* reporting banks in the listed country and are thus treated as debt assets; "total claims" are treated as foreign liabilities *owed by* reporting banks in the listed country. Data are reported as of the end of the year or for the fourth quarter.

Using data from the additional sources in Table 34, estimates of *NFA* may be reconstructed and then extrapolated for countries and years with missing data. This is done by regressing trends over time for missing components of *NFA* using data from existing years. To extrapolate a time trend for a component of *NFA*, a country must have at least 10 years of data for that component. Missing values may be extrapolated for up to 5 years. Also, only years for which data are available from at least one source in Table 34 for at least one component may be gap-filled. Where overlap exists between the Lane and Milesi-Ferretti estimates of *NFA* and the reconstructed estimates, the reconstructed estimates are screened for quality and consistency. If reconstructed estimates of *NFA* are 25% more or less than the Lane and Milesi-Ferretti estimates on average, then the reconstructed time series is discarded. Extrapolated estimates of *NFA* are only used for countries missing data for only a few years in the 1990s, such that a complete time series may be obtained for all years from 1995 or earlier to 2018. Internal gaps in time series for individual components are interpolated linearly. Countries for which *NFA* is reconstructed and extrapolated or interpolated to cover additional years include those in Table 35.

*Table 35: Countries and years for which NFA is extrapolated using data from additional sources*

| Country | Years filled |
|---|---|
| **Afghanistan** | 1997-2001 |
| **Bosnia and Herzegovina** | 1995-1997 |
| **Iraq** | 2000-2004 |
| **Marshall Islands** | 1999-2003 |
| **Montenegro** | 2002-2005 |
| **Palau** | 1995-1999 |
| **Tajikistan** | 1995-1996 |
| **Timor-Leste** | 2002-2004 |
| **Tuvalu** | 1997 |

Finally, for only two countries with missing data, *NFA* is assumed to be zero based on expert judgment by World Bank staff. These countries include those in Table 36 below.

*Table 36: Countries and years with missing estimates of NFA for which NFA is assumed to be zero*

| Country | Years filled |
|---|---|
| **Iraq** | 1995-1999 |
| **West Bank and Gaza** | 1995-2018 |

# X. Human Capital

This section explains how the lifetime income approach developed by Jorgenson and Fraumeni (1989, 1992a, 1992b) was implemented to estimate human capital wealth. According to this approach, human capital is estimated as the total present value of the expected future labor income that could be generated over the lifetime of the women and men currently living in a country (Fraumeni 2008; Hamilton and Liu 2014).

The implementation of the lifetime income approach requires data by age and gender on population, employment and labor force participation, education, earnings profiles, and survival rates. The data sources for each variable are included in Table 37**Error! Reference source not found.**. The estimation is carried out in seven steps, as described this section.

In the equations below, country and gender dimensions of variables are omitted for ease of presentation.

### Step 1. Estimating the Earnings Regressions

The World Bank's International Income Distribution Database (I2D2), a unique database of more than 2,000 household surveys maintained by the World Bank, is used to construct a database containing information on the number of people, their age, gender, earnings, educational attainment, school enrolment rates, and employment rates. This database is used to estimate the Mincerian coefficients. The Mincerian wage regressions are estimated as:

(10.1) $$Ln(w_i) = \alpha + \beta_1 e_i + \beta_2 X_i + \beta_3 X_i^2 + \mu_i$$

where $Ln(w_i)$ is the natural log of earnings for the individual $i$, $e_i$ is years of schooling (from 0 to 24), $X_i$ is labor market working experience (estimated as $AGE_i$ (from age 15 to 64) - $e_i$ - 6), $X_i^2$ is working experience-squared, and $\mu_i$ is a random disturbance term reflecting unobserved abilities. The coefficient $\beta_1$ measures the return to an extra year of schooling as the coefficients $\beta_2$ and $\beta_3$ measure the return to working experience. Since working experience shows a decreasing marginal return, in general, the coefficient $\beta_3$ is expected to be a negative value. The constant, α, measures the average log earnings of individuals with zero years of schooling and working experience. Equation (10.1) is estimated for each economy for each survey year for male and female separately.

*Table 37: Data Sources for Human Capital Wealth Calculations*

| Indicator/Variable | Data Source(s) | Notes |
|---|---|---|
| **Annual earnings** | I2D2 | Annual earnings are calculated utilizing the Mincerian regression results. The (relative) earnings profile by age, education, and gender is derived for each country and year given the corresponding data availability. |

| | | |
|---|---|---|
| **Education attainment** | I2D2 | Years of education by age and gender are derived for each country and year. |
| **Employment rates** | I2D2 | The employment rate and self-employment rate by age, gender, and education level are calculated for each country and year. These rates are calculated for employed (or self-employed) persons divided by the whole population, which includes the employed, self-employed, unemployed, and the people out of the labor force. |
| **School enrolment rates** | I2D2 | This indicates whether an individual by age, gender, and education is enrolled in school or not; used for the probability of remaining employed in future years. |
| **Employment** | ILO | The ILO employment data are used as control totals for scaling up employment from the I2D2 database. ILO employment data are also used for filling data gaps when necessary. |
| **Compensation of employees, GDP** | United Nations National Accounts database | The Compensation of Employees data are used as input to control totals for scaling up annual earnings estimates from the I2D2 database and for filling the data gaps. In addition, the GDP data are used for expressing variables as a percentage of GDP. |
| **Labor share of earnings of the self-employed** | Penn World Table database | Penn World Table estimates of the labor component of the earnings of the self-employed out of total earnings of the self-employed. Used as input to control total labor earnings. |
| **Total labor earnings** | United Nations National Accounts database and Penn World Table database | Compensation of Employees plus labor earnings of the self-employed. This combined labor earnings estimate is used as a control total for scaling up earnings estimates from I2D2 to the national level. |
| **Population** | United Nations' World Population Prospects | By gender and age groups. The distribution of workers from the I2D2 database is scaled up using the population data. |
| **Survival rates** | The GBD study from the Institute for Health Metrics and Evaluation | Survival rates are calculated utilizing the death rates obtained from the GBD study. The GBD database includes global, regional, and national age- and gender-specific mortality for 369 diseases and injuries in 204 countries and territories. |

*Note:* GBD = Global Burden of Disease; GDP = gross domestic product; I2D2 = International Income Distribution Database; ILO = International Labour Organization.

Although the I2D2 includes the number of years of schooling for most countries, some countries have data on levels of education instead of number of years of schooling. Therefore, a conversion is needed to estimate the Mincerian coefficients. In this case, including the levels of education as dummy variables in the Mincerian equation, the Mincerian coefficients are estimated for each level of education. For example, if a country's schooling data are represented as primary, secondary, and tertiary, Equation (10.1) is converted to the following form;

$$Ln(w_i) = \alpha + \beta_{1p}e_{ip} + \beta_{1s}e_{is} + \beta_{1t}e_{it} + \beta_2 X_i + \beta_3 X_i^2 + \mu_i \quad (10.2)$$

where the subscripts *p, s,* and *t* represent the levels of education (i.e. primary, secondary, and tertiary). Hence, the private rate of return to different levels of schooling (*r*) can be derived from the following equations:

$$r_p = \beta_{1p} S_p \quad (10.3)$$

$$r_s = (\beta_{1s} - \beta_{1p}) \ / \ (S_s - S_p) \quad (10.4)$$

$$r_t = (\beta_{1t} - \beta_{1s}) \ / \ (S_t - S_s) \quad (10.5)$$

where $S_p$, $S_s$, and $S_t$ stand for the total number of years of schooling for each successive level.

Wages/earnings profile by age, education and gender, $AIN_{s,a,e}$, can be readily derived for each economy/year using the following equation.

$$AIN_{s,a,e} = \exp\left(\alpha + \beta_1 e + \left(\beta_2 + \beta_3 X_{s,a,e}\right) X_{s,a,e}\right) \quad (10.6)$$

Based on the results of the Mincerian regressions, a matrix of expected earnings, *H*, is constructed. Each cell in the matrix accounts for labor earnings of the population of age '$a$', gender '$s$', and education level '$e$'. If $n_{s,a,e}$ is the number of workers of age '$a$', gender '$s$', and years of schooling '$e$', each cell in the matrix is defined as:

$$H_{s,a,e} = n_{s,a,e} \, . \, AIN_{s,a,e} \quad (10.7)$$

### Step 2. Scaling Up Earnings and Estimating Labor Earnings of the Self-Employed

For the calculation of human capital, total earnings should include not only wages but also the value of any additional benefits provided to employees, such as social security payments, health insurance, housing or other benefits in cash or in-kind. The earnings profiles from the surveys represent an underestimate of total earnings because they include only wages but not any additional benefits. To adjust for this underestimate, Compensation of Employees from the System of National Accounts (SNA) is used to benchmark survey earnings profiles. In this approach, the relative wages from the surveys matter rather than the absolute level values.

However, there is one more step needed to include all human capital. Total labor income consists of two components: the incomes of the employed and the self-employed. The earnings of the employed workers are included in the SNA under Compensation of Employees. The earnings of the self-employed are included in the SNA under Mixed Income or a more general category, Gross Operating Surplus, which includes all incomes not accruing to employees, mostly returns to capital and natural resources. The estimation of each component, and how they are used to benchmark survey earnings profiles is discussed in this section.

### *Earnings of employees*

The household surveys used for the computation of the earnings profiles—as well as the probability of working—are nationally representative. The surveys are in most cases of good quality, but they may still generate estimates that are not consistent with Compensation of Employees in the SNA (EC et al. 2009). Compensation of Employees includes the economic value of benefits, such as housing or health insurance, in addition to wages, but household surveys typically report only the wages received, thus underestimating total compensation. In some countries, additional benefits, in cash or in-kind, can be substantial. Total earnings from the survey, and the resultant human capital, are expected to be too low in comparison with the share of labor earnings in gross domestic product (GDP) because they do not include other benefits. This is addressed by using Compensation of Employees as part of the control total to scale up earnings profiles from the surveys.

### *Estimating the labor income of the self-employed*

The economic role of the self-employed can be especially important in many low- and middle-income countries where subsistence agriculture and informal economy are very common. However, the earnings of the self-employed are not well represented in the national accounts of many countries because, with few exceptions, Compensation of Employees includes only workers who are formally employed. The earnings of the self-employed are included as part of another category, Mixed Income or Gross Operating Surplus, which also includes income accruing to produced capital and natural resources (resource rents). Earnings of the self-employed workers may also be poorly represented in household surveys.

Correcting this omission requires i) identifying the earnings that can be attributed to the self-employed and ii) distinguishing the labor component of earnings from returns to other factors of production, which are all combined. For human capital estimates, only the labor portion from the earnings of the self-employed should be included. The Penn World Table (PWT) database has made estimates of the labor component of the income of the self-employed (Feenstra et al. 2015), which is described in the following text.

For the purpose of disaggregating the earnings by employment, we used the shares of labor income of employees and self-employed from the PWT data on total compensation of labor except for China where its income group average was used[26]. The PWT data on total compensation of labor construct a 'best estimate' labor share based on four options for adjustment, discussed below, to estimate the shares of labor income of employees and self-employed.

The first two adjustment estimation methods proposed by PWT are used for countries that report mixed income as a separate income category in national accounts, roughly 60 countries. Mixed income isolates total income earned by self-employed workers from resource rents and returns to produced capital by other producers. Mixed income combines both capital and labor income accruing to the self-employed, and can be considered as an upper bound to the amount of labor income earned by the self-employed. The two adjustment methods are:

1) All mixed income is allocated to labor assuming self-employed workers only use labor input.

2) Half of the mixed income is allocated to labor assuming self-employed workers use labor and capital in the same proportion.

The third adjustment method assumes the self-employed earn the same average wage as employees. However, this method has some drawbacks for countries where the share of employees in the labor force is low. Assuming self-employed earn the same average wage as employees will overstate the labor income of the self-employed in those countries. In particular, in most low-income countries agriculture employs about half of the self-employed. This leads to the fourth adjustment method, which is based on the share of agriculture in GDP. Total value added in agriculture is considered a good enough proxy for the labor earnings of the self-employed.

As explained all four methods have some drawbacks, and therefore the Penn World Table data on total compensation of labor construct a 'best estimate' labor share. Adjustments based on mixed income are applied where available since the mixed income captures the income of self-employed. The second adjustment method is preferable since the first adjustment method assumes no use of produced capital by the self-employed. The third and fourth adjustment methods are used if there is no mixed income data and the share of labor compensation of employees is below 0.7.

### *Total labor earnings*

The PWT database has made estimates of the labor component of the earnings of the self-employed, which we add to Compensation of Employees to produce the control total for total labor earnings to scale up survey-derived earnings profiles by age, gender, and years of education. This approach implicitly assumes that the demographic and earnings profiles of the self-employed are the same as employee workers in formal labor markets. Although we know that is unlikely, there is insufficient data with global coverage to refine treatment of the self-employed at this time.

[26] Official data on labor income for China includes income of both employed and self-employed workers.

The total labor compensation (*W*) consists of two parts: (*comp_employ*) + (*comp_self*). By using the PWT data, it can be calculated as the following:

(10.8) $$W = comp_{employ} + comp_{self} = LABSH * GDP$$

(10.9) $$comp_{employ} = LABSH_{employ} * GDP$$

(10.10) $$comp_{self} = LABSH_{self} * GDP$$

where $LABSH$[27], $LABSH_{employ}$ and $LABSH_{self}$ represent the total labor share (including both employees and the self-employed), labor share of employees and self-employed, respectively. Therefore, $comp_{employ}$ and $comp_{self}$ stand for total compensation of employees and self-employed, respectively.

We also assume that the annual labor income ($AIN_{s,a,e}$) is the same for both employees and the self-employed and is estimated by using information for employees in the I2D2 database (equation 10.6). Then the following adjustment can be made:

(10.11) $$\sum_{s,a,e}\left[\overline{AIN}_{s,a,e} * n_{s,a,e}\right] = W ,$$

where $n_{s,a,e}$ , as before, includes the number of people for both employees and the self-employed, and $\overline{AIN}_{s,a,e}$ is the after-adjustment annual income. $\overline{AIN}_{s,a,e}$ is estimated as follows:

(10.12) $$\overline{AIN}_{s,a,e} = \frac{W}{\sum_{s,a,e}\left[AIN_{s,a,e} * n_{s,a,e}\right]} * AIN_{s,a,e}$$

After the lifetime income ( $h_{s,a,e}$) for each cell (by gender *'s'*, age *'a'* and education *'e'*) has been derived (as described in step 6), one can apply the I2D2 sample share of the self-employed to the corresponding population data to generate the human capital for the self-employed.

In other words, the human capital for total employed (employees + self-employed) is calculated first by using the adjusted annual income profiles as shown in equation (10.12). Then among the calculated total human capital, the part contributed by the self-employed can be separately estimated.

### Step 3. Filling the Data Gaps

Since the estimations rely on labor force and household surveys, it is important to have at least one survey for each year and each country. Unfortunately, this is not the case for most countries. Moreover, some countries have only one survey for the entire period. Therefore, filling the data gaps is a crucial step for

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[27] The LABSH variable in the PWT is expressed as a share of GDP at basic prices. Therefore, when incorporated in the human capital wealth calculations, LABSH is multiplied by an adjustment factor, reflecting the ratio of GDP at basic prices to GDP at market prices. Thus, the resulting LABSH is expressed as a share of GDP at market prices and used accordingly in equations (10.8)-(10.10).

the human capital wealth calculations. Even though the current method for filling the gap has some drawbacks, it is useful.

To fill the data gaps, the estimated Mincer parameters and I2D2 sample employment and enrollment rates for the survey year are held constant until the next available survey year, and control totals for earnings for each of the intervening years are used to generate the human capital estimates for the years between two survey years. For example, if there exists only one survey for a country, the parameters of this one survey are used for the entire period. If there exist three surveys (for example, 1995, 2000, and 2010) for 1995–2018, the parameters from 1995 are used for 1995–1999, the parameters from 2000 are used for 2000–2009, and the parameters from 2010 are used for 2010 and onward.

*Table 38: Countries and Number of I2D2 Surveys*

| Survey Count | # of countries |
|---|---|
| **1** | 29 |
| **2** | 15 |
| **3** | 12 |
| **4** | 14 |
| **5** | 5 |
| **6** | 7 |
| **7** | 6 |
| **8** | 3 |
| **9-11** | 8 |
| **12** | 11 |
| **13** | 15 |
| **14-19** | 10 |
| **20 or more** | 11 |
| **Total** | **146** |

*Note*: I2D2 = International Income Distribution Database.

Obviously, there are significant problems associated with this method. First, an occasional jump occurs between human capital estimates from a non-survey year to a survey year. For example, if there are surveys for 2000 and 2010, all the data gaps for 1995-1999 are filled with the parameters of the 2000 as the parameters of the 2010 survey are used for filling the gap for 2001-2018. So, a jump could occur between human capital estimates of 2000 to 2001. In addition, if there is only one survey, all the period must be estimated with one survey data and this doesn't allow policymakers to see the effects of policy changes if any.

### Step 4. Scaling Up the Employment and Population

Since the survey data do not capture the whole population, the data from the surveys are adjusted to population estimates from the United Nations to ensure that estimates are adequate.

If $n_{s,a,e}$ is the number of workers of age *'a'*, gender *'s'*, and years of schooling *'e'*, and *P* is the total number of population of a country received from the United Nation's World Population Prospects, the scale parameter $\alpha$ is calculated as:

(10.13)
$$\alpha = \frac{P}{\sum_{s,a,e}[n_{s,a,e}]}$$

Thus, the scaled number of workers of age *'a'*, gender *'s'*, and years of schooling *'e'*, $N_{s,a,e}$ , is calculated as:

(10.14)
$$N_{s,a,e} = \alpha * [n_{s,a,e}]$$

### Step 5. Calculating Survival Rates for Each Country

Survival rates utilize death rates obtained from the Global Burden of Disease Study (GBD)[28]. The GBD database includes global, regional, and national age- and gender-specific mortality for 369 diseases and injuries in 204 countries and territories for 1990–2019. Survival rates are calculated as:

(10.15)
$$v_{a+1} = 1 - death_a$$

where $v_{a+1}$ is the probability of surviving one more year at age '*a*', and $death_a$ is the death rate at age '*a*'. Equation (10.15) is calculated for each country for each survey year for male and female separately.

### Step 6. Calculating the Lifetime Income

Two stages in the life cycle of an individual of working age are distinguished: ages 15-24 and ages 25-65. The main assumption here is that individuals ages 15–24 have the possibility to receive further education, while those ages 25–65 are assumed to have no such possibility. Based on this assumption, the lifetime labor income of an individual is calculated as follows:

- Persons aged 25-65

(10.16)
$$h_{s,a,e} = p^m_{s,a,e} w^m_{s,a,e} + p^s_{s,a,e} w^s_{s,a,e} + d * v_{s,a+1} * h_{s,a+1,e}$$

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[28] The Global Burden of Disease Study 2019 database is used for the human capital calculations. http://www.healthdata.org/gbd/2019.

- Persons aged 15-24

$$h_{s,a,e} = p^{m}_{s,a,e} w^{m}_{s,a,e} + p^{s}_{s,a,e} w^{s}_{s,a,e} + \left(1 - r^{e+1}_{s,a,e}\right) * d * v_{s,a+1} * h_{s,a+1,e} + r^{e+1}_{s,a,e} * d * v_{s,a+1} * h_{s,a+1,e+1} \ . \quad (10.17)$$

In these equations $h_{s,a,e}$ is the present value of the lifetime income for an individual with age of '*a*', gender *'s',* and education of '*e*', $p^{m}_{s,a,e}$ is the probability to be employed, $w^{m}_{s,a,e}$ is the received compensation of employees when employed, $p^{s}_{s,a,e}$ is the probability to be self-employed, $w^{s}_{s,a,e}$ is the received compensation of employees when self-employed, $r^{e+1}_{s,a,e}$ is the school enrolment rate for taking one more year's education from education of '*e* ' to one-year higher level of '*e+1*', $d$ is the discount factor and $v_{a+1}$ is the probability of surviving one more year.

Equations (10.16) and (10.17) suggest that the lifetime income of a representative individual consists of the current labor income and the lifetime income in the next year. The current labor income is adjusted by the probabilities of being either employed or self-employed, and the lifetime income in the next year is adjusted by a discount factor and the corresponding survival rate. In addition, for an individual aged 15-24, there are two courses of action: first holding the same education level and continue to work, and second taking one more year education and earn income after completing the education.

The probabilities of being either employed ($p^{m}_{s,a,e}$) or self-employed ($p^{s}_{s,a,e}$) can be approximated by the employment rate or self-employment rate for people with age of *'a'*, gender *'s'*, and education of *'e'*. Note that these rates have to be calculated by the employed (or self-employed) persons divided by the whole population that includes the employed, self-employed, unemployed, and the people out of the labor force. The sample ratios from the I2D2 database are used.

The empirical implementation of equations (10.16) and (10.17) is based on backwards recursion. This suggests that the lifetime labour income of a representative individual aged 65 is zero since it is presumed that there is no working life after the age 65. Therefore, the lifetime labour income of a person aged 64 is her current labour income. Likewise, the lifetime labour income of a representative individual aged 63 is sum of her current labour income and the present value of the lifetime labour income of a person aged 64. Hence, the present value of the lifetime income matrix is created for an economy by applying the backwards recursion to equations (10.16) and (10.17).

Human capital is calculated under the assumption that labor earnings grow at a constant rate g over the working lifetime. Because of the efficiency differences among the income groups and regions, region- and income group–specific annual real labor earnings growth rates are applied. The growth rates are derived from the World Bank's macroeconomic and fiscal model based on historical data and long-term projections based on potential output in each country, which builds on total factor productivity growth, capital stocks, and employment growth. In addition, average long-term wage growth rates are capped at 4 percent (Table 39). Furthermore, it is assumed that real labor wage growth rates are constant over time during the lifetime.

In addition, labor income growth for 2020–22 is revised down to adjust for the short-run effects of the COVID-19 pandemic on wages. For the period after 2023, a recovery in the labor income growth rates is assumed to be aligned with the recovery in total factor productivity growth. The growth rates for labor income used in the human capital calculations are provided in Table 39.

In addition, in calculating the net present value, a uniform discount rate of 4 percent is used for human capital in line with all resources and countries within the wealth accounting framework.

*Table 39: Labor Income Growth Rates, by Region and Income Level*

| Region | Countries | Wage growth (%) |
|---|---|---|
| **East Asia and the Pacific, high-income** | 4 | 1.08 |
| **East Asia and the Pacific (excluding high-income)** | 11 | 4.00 |
| **Europe and Central Asia, high-income** | 27 | 1.08 |
| **Europe and Central Asia (excluding high-income)** | 17 | 2.83 |
| **Latin America and the Caribbean, high-income** | 4 | 1.08 |
| **Latin America and the Caribbean (excluding high-income)** | 20 | 0.96 |
| **Middle East and North Africa, high-income** | 7 | 1.08 |
| **Middle East and North Africa (excluding high-income)** | 10 | 1.34 |
| **North America** | 2 | 0.91 |
| **South Asia** | 6 | 3.60 |
| **Sub-Saharan Africa** | 38 | 1.41 |
| **TOTAL** | **146** | |

*Source:* World Bank staff calculations.
*Note:* All countries in North America are high-income; all countries in South Asia and Sub-Saharan Africa are low- or middle-income.

### Step 7. Generating the Lifetime Income for All People in an Economy

The calculations from step 1 to step 6 generate the lifetime income profiles for a representative individual cross-classified by age, gender, and education. The lifetime income profiles for a representative individual are multiplied by the corresponding number of people in a country, and thus the human capital stock by age, gender, and education is calculated.

Summing up the stocks of human capital across all classified categories generates the estimate of the aggregate value of the human capital stock for each country:

(10.18)
$$HC = \sum_{s,a,e} [h_{s,a,e}] * pop_{s,a,e}$$

where $HC$ is the human capital stock, $h_{s,a,e}$ is the present value of the lifetime income for an individual with age of '*a'*, gender *'s'*, and education of '*e'*, and $pop_{s,a,e}$ is the population of age '*a'*, gender *'s'*, and education level '*e'*.

# XI. Total Wealth

Total wealth is calculated by summing up each component of wealth ("bottom-up approach"):

$$Total\ wealth = Natural\ capital + Produced\ capital + Human\ capital + Net\ foreign\ assets$$

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