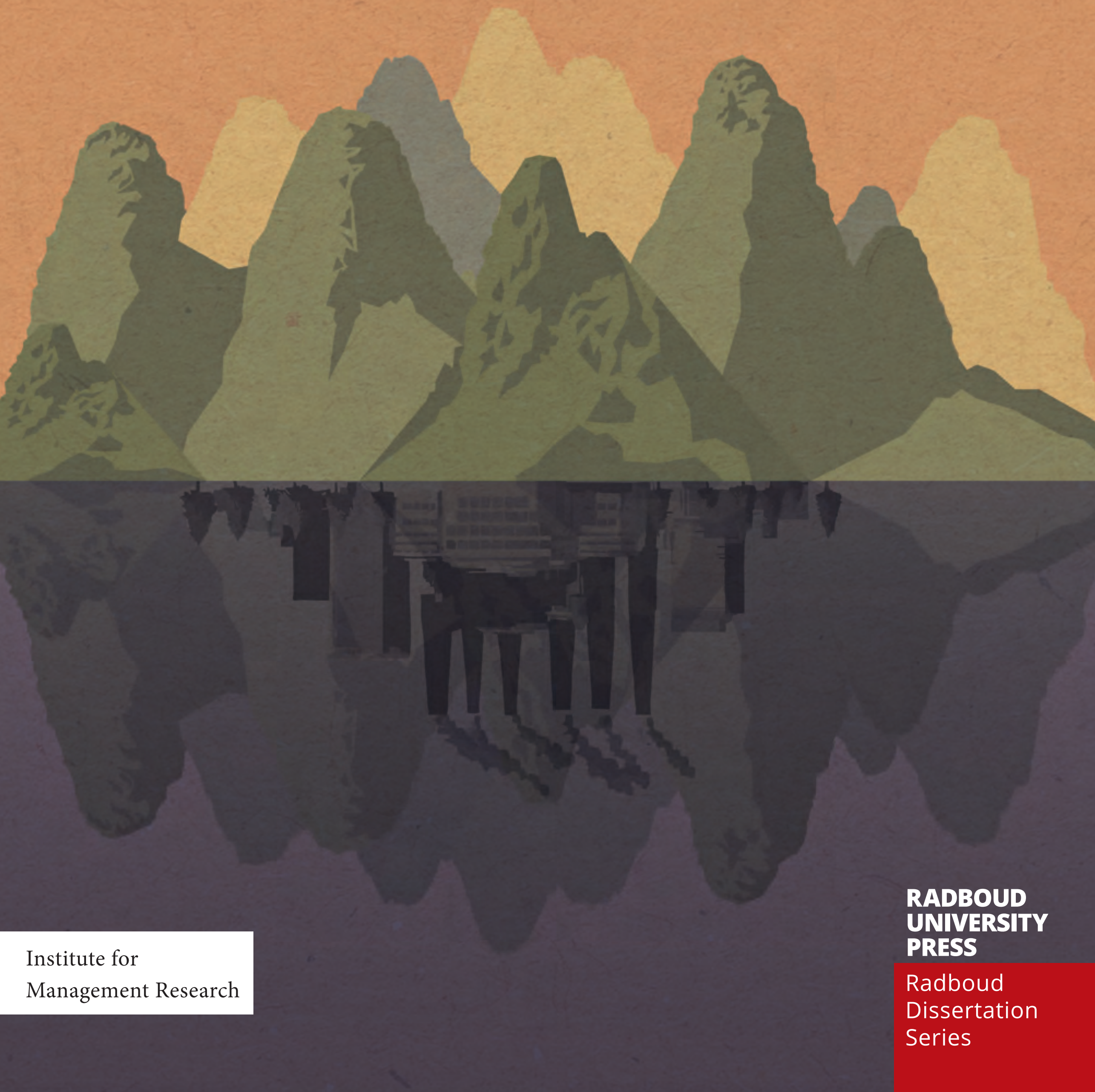
Natural resource conversion for sustainable development

Charan van Krevel



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Natural resource conversion for sustainable development

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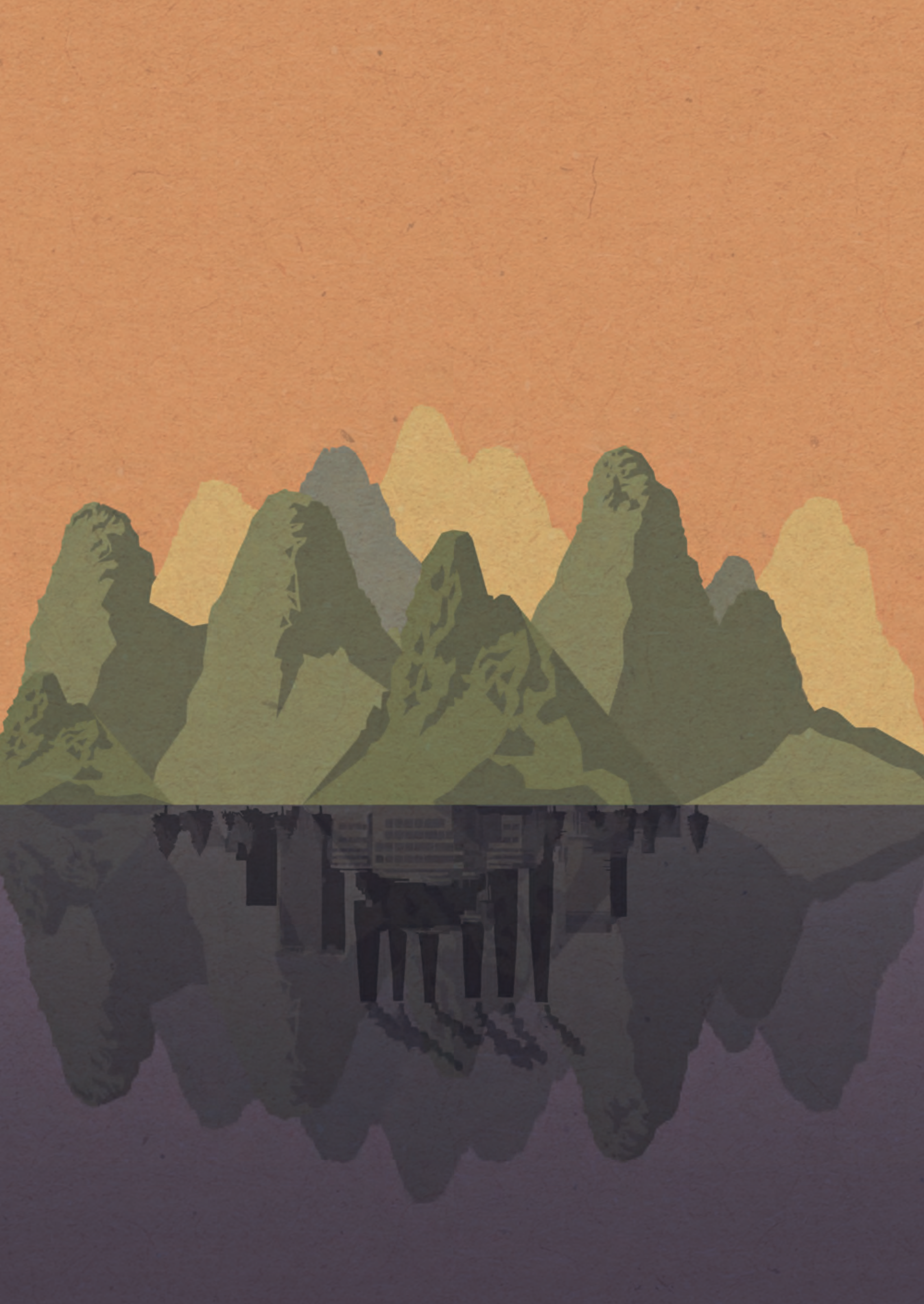

Chapter 1.

Introduction

1.1. The aim, scope, and organization of this dissertation

Sustainable development has become ubiquitous, as evidenced by, for instance, the Sustainable Development Goals, annual climate summits, and widespread climate protests. These developments are a response to, among other things, the detrimental effect of economic activities on the environment. The world is gearing up to transition toward a greener economy with less ecological strain and fewer harmful emissions. To this end, many countries pledge to have zero net emissions by 2050, requiring a shift from dirty hydrocarbon fuels towards clean energy generation, storage, and deployment. The transition necessitates mining new metals and minerals, many of which can be found in developing countries. These countries enter a window of opportunity to leverage their natural resources for sustainable development and prosperity. However, seeking sustained prosperity in resource-rich developing countries may conflict with the ambition to cause less ecological strain, creating a potential trade-off. How can countries exploit their natural resources in a way that contributes to sustainable development?

This dissertation *aims to understand better the relationship between natural resource exploitation and sustainable development*. The latter is commonly defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987, p. 54). From an economic perspective, sustainable development entails passing on more factors of production to the next generation than we inherit from the last. This perspective has come to be known as the capital approach to sustainability (Pearce and Atkinson 1993). The approach asserts that increasing the stock of human, produced, and natural capital assets increases the capacity of future generations to meet their needs. The more assets a generation owns, the more utility they can yield directly and indirectly through their contributions to the goods and services they help produce.

According to the capital approach, natural resource-exploiting countries can develop sustainably by following the so-called generalized Hartwick rule (Hamilton 1995). The rule prescribes that the loss of natural capital assets should be offset by an equal or greater accumulation of human, natural, or produced capital assets. For instance, the extraction of exhaustible natural resources such as fossil fuels or minerals generates natural resource revenues, which can be reinvested in education or health to accumulate human capital assets. Similarly, natural resource revenues can be invested in produced capital assets (e.g., buildings, infrastructure, machines, and other tools) or other natural resources (e.g., reforestation, fisheries, agriculture). Following the generalized Hartwick rule, it is possible, at least in theory, to convert natural capital into other assets that promote well-being. Sustainable development results when the value of capital accumulation offsets the loss of depleted natural capital. Therefore, natural resource conversion has the potential to allow resource-rich countries to leverage natural resources and promote the well-being of their future generations.

Despite the need to explore whether countries succeed in converting natural capital as described by the Hartwick rule, studies on the topic are scarce. This dissertation addresses the gap by conducting four empirical studies in two parts, each containing two studies (Table 1.1). Part I features two chapters that explore how sustainable development is associated with countries' initial level of development and presence of natural resources (Chapter 2) and the depletion of natural resources within countries (Chapter 3). Part II comprises one macro- and a micro-level study, respectively, unpacking the process of natural resource conversion (Chapter 4) and the role of public spending by governments in the conversion process (Chapter 5).

Table 1.1. Schematic overview of chapters, content, scope, and data

	Topics	**Dependent variable**	**Independent variable(s)**
		Part I	
Chapter 2	Long run convergence and sustainable development	Inclusive Wealth growth	Natural capital abundance
Chapter 3	Cross-country estimates of natural resource conversion	Inclusive Wealth growth	Natural capital depletion
		Part II	
Chapter 4	Unpacking cross-country heterogeneity in natural resource conversion	Genuine Savings	Various
Chapter 5	Reinvesting natural resource revenues sustainably	Fiscal expenditures on relevant public services	Exogenous natural resource windfalls

Chapter 2 explores the association between the initial level of development and sustainable development across 140 countries between 1990 and 2010. Sustainable development is measured by the growth of the United Nations' Inclusive Wealth indicator (UNU-IHDP-UNEP 2015), comprising countries' stock of human, produced, and natural capital. The chapter considers cross-country convergence measured by per capita Inclusive Wealth. The study uncovers a worrisome pattern. Countries' sustainable development paths diverge, despite national income convergence in the short-term. Countries rich in natural capital, in particular, are not catching up developed countries. Instead, their standards of living are projected to deteriorate in the long run.

Chapter 3 presents a panel data analysis of how natural resource depletion affects sustainable development. Drawing on the same panel of 140 countries, a within-country analysis finds that natural capital depletion correlates positively with sustainable development. The rate of Inclusive Wealth growth increases as countries deplete more natural capital. The finding provides necessary but not sufficient evidence for natural capital conversion. It either means that natural resources are converted sufficiently or that insufficient conversion hampers sustainable development at a decreasing rate. To make more sense of these results, the studies in Part II examine the process of natural resource conversion in more detail.

Chapter 4 examines empirically how four indicators of natural resources that approximate the four stages of natural resource conversion—exploration, extraction, appropriation, and reinvestment—affect sustainable development. Employing a panel of 126 countries from 1980 to 2018, the chapter finds a joint negative causal effect of oil, gas, and coal rents (corresponding to the extraction stage) and exports (corresponding to the appropriation stage) on sustainable development. However, countries with good institutions are able to use oil, gas, and coal extraction and exports for sustainable development, indicating successful natural resource conversion.

Chapter 5 studies the final stage of the conversion process: the reinvestment of natural resource revenues. The analysis utilizes a policy in Indonesia that creates plausibly exogenous temporal fluctuations in natural resource tax revenues for causal inference. Typically, governments are the primary investor in human, produced, and natural capital assets. Their fiscal spending on health, education, the environment, and the economy helps accumulate these assets. The study assesses to what extent governments spend natural resource revenues accordingly. By adopting a micro-level perspective, the chapter provides causal evidence that Indonesian local governments' spending patterns promote sustainable development. Upon receiving additional natural resource revenues, local politicians tend to spend them on public goods and services that contribute to sustainable development.

In this section, I have discussed the dissertation's aim, scope, and outline. The following section of this chapter examines the conceptual foundation of this thesis—the capital approach— in more detail. Specifically, the section aims to clarify how the approach is quintessential to understanding sustainable development from the viewpoint of economics. It then discusses the data considerations arising from the capital approach, which are central to the empirical analyses.

1.2. The economics of sustainable development

1.2.1. The capital approach to sustainable development

There is a need to move away from focusing on short-term economic gain and instead consider how to preserve the well-being of future generations (Costanza et al. 1992; Stiglitz et al. 2009). Nobel Laureates Kenneth Arrow, Joseph Stiglitz, William Nordhaus, and Amartya Sen have all expressed concern with the diminishing ability to meet humankind's needs sustainably. The prioritization of sustainable development by the United Nations underlines the urgency of this issue (General Assembly 2015), although attention towards it is not recent. Its origins go back to the Club of Rome's publication, The Limits to Growth (Meadows et al. 1972). The report cautions that the patterns of economic growth across the world are unsustainable due to the damages caused by resource depletion and environmental degradation. Since the Club of Rome, a body of academic literature on sustainable development has emerged that addresses the growing concerns about societies' ability to develop sustainably (Arrow et al. 2012).

The prioritization of sustainability carries significant implications for economics, especially when measuring development. The definition of sustainable development, as proposed by the Brundtland Commission, implies *intergenerational well-being* (Dasgupta and Maler 2000). The latter concept is absent from commonplace measures of economic performance that prioritize the present, such as Gross National Income and Gross Domestic Product. The question is not only whether an economy achieves current well-being but also how it affects the *potential* well-being of future generations (Arrow et al. 2012).

Economists suggest that the well-being of future generations depends on the resources they inherit, including factors of production and well-being contributors (Hamilton and Ruta 2007; Stiglitz et al. 2009).[1] The capital approach operationalizes this idea by advocating for the transfer of *inclusive wealth*,[2,3] the stock of economically valuable capital assets, to succeeding generations (Pearce and Atkinson 1993). Inclusive wealth comprises three main capital types: (1) exhaustible and renewable natural capital, (2) produced capital (e.g., buildings, machines, and infrastructure), and (3) human capital.

Inclusive wealth growth contributes to well-being directly and indirectly. First, capital contributes directly to well-being (UNU-IHDP-UNEP 2015). Better education, natural resources, and manufactured capital assets enrich our lives. The more and better-quality assets we pass on to future generations, the more direct benefits they can enjoy. Second, a growing productive base broadens future consumption possibilities (Hamilton and Ruta 2007). The present value of inclusive wealth equals the present value of all future consumption that can be derived from it (Fisher 1906). Hence, inclusive wealth growth expands the potential to achieve utility from via consumption—thus indirectly.

Countries develop sustainably when inclusive wealth is non-declining, suggesting future generations have an equal or greater capacity for well-being than the current one (Pearce and Atkinson 1993). Therefore, sustainable development *is* inclusive wealth growth (Stiglitz et al. 2009). If the stock of inclusive wealth diminishes, it signals an inevitable reduction in potential future well-being. In other words, an economy is functioning unsustainably. On the other hand, a positive trend points towards a sustainable development path.

1. Of course, natural scientists, ecologists, and other disciplines may argue that different things should be sustained.
2. The concept of inclusive wealth is also called comprehensive wealth. These terms are used interchangeably in the literature. Moreover, there are two empirical indicators measuring the concept. The U.N. has Inclusive Wealth and the World Bank has Comprehensive Wealth. Their empirical methodologies are discussed later. To avoid confusion when reading this thesis, I will employ inclusive wealth as a concept and Inclusive Wealth as an indicator and avoid comprehensive wealth as a term as much as possible.
3. Coincidentally, Inclusive Wealth is the quantitative measure on which the Brundtland Commission based the idea of sustainable development (Dasgupta et al. 2021)

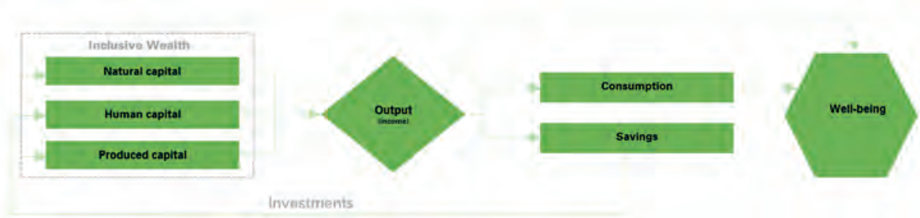

Figure 1.1. The capital approach: wealth, well-being, and sustainability

Measuring sustainable development amounts to taking stock of changes in human, produced, and natural capital (Stiglitz et al. 2009). Inclusive wealth grows when there is a net positive investment. Investments in education build human capital, while those in tangible assets contribute to the growth of produced capital. Similarly, resources allocated to renewable natural resources accumulate natural capital. Simultaneously, capital assets gradually depreciate. Natural resources are physically integrated into (capital) goods (Daly 2020). Produced capital physically decays or loses socio-economic value. Human capital naturally diminishes over time as educated and healthy people eventually pass away. Ultimately, what matters for sustainable development is the net outcome of investments and depreciation.

Hence, natural capital depletion does not necessarily jeopardize future generations' well-being. If revenues from resource exploitation are reinvested sufficiently then inclusive wealth can grow (Hamilton 1995; Hamilton and Hartwick 2014). This idea—the generalized Hartwick rule—requires saving and reinvesting enough income to overcome the losses of natural capital depletion (see Figure 1.1). The possibility of compensating investments, therefore, assumes that capital assets are substitutable.[4] Natural resource exploitation need not be a curse for sustainable development if the post-extraction process is handled carefully.

Although sustainable development is identical to inclusive wealth growth in theory, measuring sustainability is far from trivial. Estimating the values of human, produced, and natural capital presents enormous data challenges. The following section discusses the progress and limitations of the three main initiatives to quantify sustainable development.

4. The feature is a source of debate among ecologists who argue that not all natural resources are substitutable and economists (Ayres et al. 2001; Dietz and Neumayer 2006). Indeed, the ozone layer and ocean currents are irreplaceable aspects of the environment. At the heart of this long-lasting debate are two camps with differing ethical valuations of the economy versus the environment.

1.2.2. Indicators of sustainable development

There are two approaches to measuring inclusive wealth growth (i.e., sustainable development). The first targets the investment and depreciation *flows* of the three capital types. The second estimates the value of the inclusive wealth *stock* and tracks its changes over time. In theory, both methods should yield identical results. However, calculating the economic value of every human, manufactured asset, and natural resource—down to each plot of land, tree, and mineral deposit—is a monumental challenge due to impossible data requirements. The three main datasets discussed below take on the challenge differently, leading to variations in their estimates.

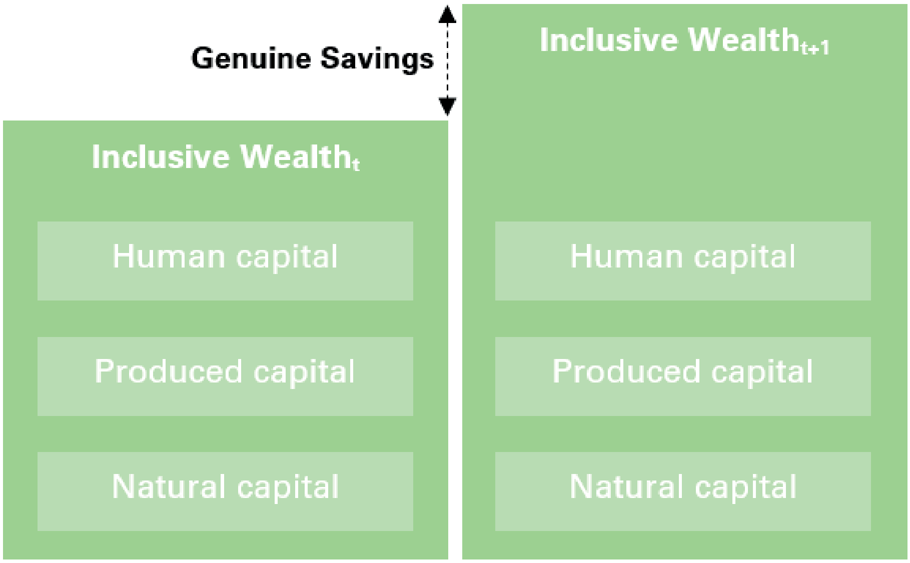

Figure 1.2. The relationship between Inclusive Wealth and Genuine Savings

Genuine Savings (GS) is the pioneering effort to measuring sustainable development (Hamilton and Clemens 1999). It uses the first approach: measuring net human, produced, and natural capital investments to approximate sustainable development. Calculating the net change of produced capital, for instance, involves determining gross savings, a rough approximation of produced capital investments, and subtracting its depreciation rate. Applying the same logic to natural and human capital yields a measure of inclusive wealth growth.

GS offers several advantages for empirical research. It is a proven suitable sustainable development indicator over extended periods (Greasley et al. 2014; Hanley et al. 2015). Its established use as the first wealth-based sustainable development metric cultivated a substantial body of literature. Since the publication of the initial estimates twenty-four years ago, continuous efforts have refined its methodology (e.g., Atkinson and Hamilton 2007). GS remains part of an active research field as the most frequently used indicator for sustainable development of the capital approach (e.g., Lindmark et al. 2018; Cook and Davíðsdóttir 2021). Moreover, GS data span longer than the alternative indicators that cover only one generation. For certain countries, GS estimates reach 1850 (McLaughlin et al. 2023). Consequently, GS is an excellent indicator for sustainable development when broad coverage and comparability to other studies are essential.

Inclusive Wealth (IW) (UNU-IHDP-UNEP 2015) and Comprehensive Wealth (CW) (World Bank Group 2022) are modern, comprehensive initiatives for measuring sustainable development.[5] Unlike GS, IW and CW track both the absolute levels and changes in all capital stocks. The indicators value assets in real dollar terms adjusted for purchasing power parity to enable cross-country comparisons of their economic utility. As a result, IW and CW offer more complete data than GS does. The main advantage for empirical research is the stock level estimates, indicating current and future generations' potential to experience well-being (Polasky et al. 2015; Van den Bergh 2022). In contrast, GS only conveys annual changes, sufficient for measuring sustainable development but not much more.

Key differences between IW and CW arise from their methodologies, especially in dealing with the stringent data limitations of valuing every capital asset worldwide. CW has certain advantages. It accounts for financial capital, representing a country's net position in international debt. The rationale is that financial assets be transformed into human, produced, or natural capital assets after debt collection. Additionally, in its latest iterations, CW includes a more complete list of natural resources such as mangroves, fisheries, and protected land areas.[6] Lastly, CW provides annual data, compared to IW's five-year intervals, allowing for granular tracking of sustainable development over time.

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5. Recall, capital letters indicate empirical indicators, whereas lowercase letters indicate the concept.
6. Notably, some of the valuation methods used for these additional natural resources are questionable. For instance, it is assumed that mangroves are simply not in decline, even though little empirical evidence supports this assumption.

However, CW's weaknesses render its data less appropriate for this thesis than IW. One drawback is its reliance on annual market prices for valuing natural resources. Relying on fluctuating market prices can lead to paradoxical situations. For example, a country may appear to be developing sustainably despite heavily extracting fossil fuels and without any compensating reinvestments. Remaining fossil fuel reserves may appreciate beyond their initial values when countries artificially inflate fossil fuel prices. As a result, even unsustainable oil states appear sustainable.[7] What matters most for understanding natural resource conversion is tracking the biophysical depletion of natural capital, which is obscured in CW's methodology.

In contrast, IW assigns a constant social value to natural resources over the sample period, ensuring that only the biophysical changes influence sustainable development. Consequently, natural capital depletion contributes to sustainable development only when offset by a biophysical accumulation of human, produced, or natural capital assets. It does not respond to whimsical price fluctuations and idiosyncratic shocks. Consequently, IW is more reliable than CW for studying natural resource conversion.

Hence, the studies use either GS or IW. Chapter 2 and Chapter 3 require natural capital *stock* estimates and, therefore, employ IW data. Chapter 2 studies the relationship between the value of the natural capital stock and the rate of Inclusive Wealth growth (i.e., sustainable development). GS is inapplicable to this analysis because it does not provide absolute values for capital stocks. Chapter 3 considers how natural capital depletion (i.e., decline of biophysical units, in contrast to depreciation of natural resource values) contributes to sustainable development. GS does not truly measure natural capital depletion (Boos 2015; Dietz and Neumayer 2006; Pillarisetti 2005). Instead, what it considers 'natural capital depreciation' is calculated using resource rents in the market, which fails to reflect accurately the true social value of depleted natural capital and change annually. Therefore, IW data are used in these chapters.

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7. Additionally, annual revaluations should also track other sources of value changes, such as the risk of becoming a stranded asset, which is an asset that has become economically unviable before its natural end-of-life due to external factors (often political, but in this case, ecological). However, the calculation methods needed to monetize the risk of global stranded assets are not yet fully developed. The ambition of the project to use up-to-date, accurate prices is infeasible at present.

Chapter 4 employs GS data because it requires extensive time coverage and better comparability to extant literature. The analysis studies the natural resource conversion process, focusing variables its approximate the four stages. Previous literature has only used a single variable to approximate the whole process and ignored the real-world, staggered practice of natural resource conversion. A large panel is needed, hence, Chapter 4 benefits from GS for its coverage over an extended period (39 years) and comparability to existing literature. Chapter 5 employs other data as it does not measure sustainable development directly. Instead, it focuses on government expenditures that contribute to inclusive wealth growth.

In the previous section, I discussed this dissertation's conceptual background and associated empirical initiatives. The following section embeds this thesis in the literature on the relationship between natural resource exploitation and sustainable development. First, I review the literature that studies natural resources and development, as it highlights the developments and issues relevant to this thesis. Then, the section scrutinizes the extant literature on the relationship between natural resource exploitation and sustainable development.

> *"I wish we had found water."*
> *Sheik Ahmed Yamani, former Saudi oil minister*

1.3. The economics of natural resource exploitation

1.3.1. A brief history of the resource curse literature

The relationship between natural resources and economic development is studied since the founding of modern economics. Adam Smith's *Wealth of Nations*, published in 1776, emphasizes the importance of capital accumulation—the driving force behind economic growth, he says. Smith argues that natural capital, which he broadly defines as mines, fisheries, and land, is a necessary input for the production of manufactured capital assets. It further increases labor productivity, leading to output growth (Wolloch 2020). Without natural resources, there is no development.

Smith and his contemporaries established natural capital's pivotal role in driving prosperity. Although their ideas on natural resources are not original, they shape a dominant, optimistic outlook.[8] This outlook stems from a Eurocentric worldview focused on the Western industrial perspective (Wolloch 2020). The view was so prevalent that John F. Kennedy's statement is emblematic of the intellectual climate (1963): "*This country has become rich because nature was good to us.*"

The so-called 'golden age of resource-based development' (1870-1930) reinforces the positive outlook. It is a prosperous period in the United States and beyond, thanks to abundant agricultural land, rich minerals, ores, coal, and oil (Barbier 2011).[9] Natural resources are a blessing, and that sentiment persists until the mid-20th century (e.g., Rostow 1959; Viner 1953) (see Figure 1.3).

However, the introduction of the resource curse challenges the paradigm. This hypothesis suggests that countries with abundant natural resources, such as oil, natural gas, and minerals, tend to have lower economic growth and worse development outcomes than countries with fewer natural resources (Badeeb et al. 2017, p. 124). The phenomenon is also called the 'paradox of the plenty', as it seems counterintuitive that countries with more resources have an economic disadvantage.

Krugman (1987) develops a theoretical rationale for the resource curse. Gelb (1988) and Auty (1993) pioneer empirical resource curse research in the 1980s and 1990s. Contrasting the dominant view since Adam Smith, Gelb shows that oil-abundant countries form domestic capital less efficiently than non-oil-abundant countries between 1971 and 1983. Auty extends this relationship to all natural resources. He argues that resource endowments hamper industrialization, suggesting it stunts development.

Sachs and Warner's (1995) seminal work is arguably "the first scholarly work confirming the adverse effects of resource dependence based on empirical evidence" (Badeeb et al. 2017, p. 124). They conduct a series of cross-sectional studies (Sachs and Warner 1995, 1997, 1999, 2001) and find that natural resource-dependent countries develop more slowly. Subsequent

8. The physiocrats, Smith's intellectual predecessors, held that nature provides surplus value which fuels economic growth (Brue and Grant 2012). In modern terms, they believe all human and produced capital is inextricably derived from nature.

9. I define a period as a range of time in which there is a dominant view in the literature on the relationship between natural resources and development.

studies (e.g., Gylfason et al. 1999; Gylfason 2001; Ross 2001; Sala-i-Martin and Subramanian 2013) corroborate this finding using new datasets. After the negative relationship is established empirically, the literature shifts its focus to the mechanisms underlying the resource curse. The literature that spawns is so deep that it is thoroughly explored by several surveys (e.g., Badeeb et al. 2017; Deacon 2011; Frankel 2010; Ross 2015; Van der Ploeg 2011; Venables 2016).

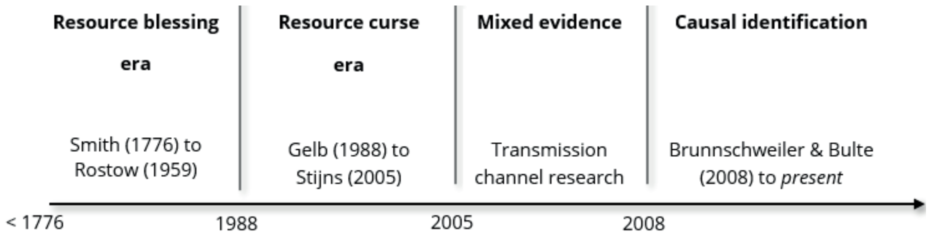


Figure 1.3. Periods of scientific inquiry into the economic effects of natural resources

Table 1.2. Overview of the multitude of empirical indicators of natural resources

Empirical Indicator	Description	Literature
Natural resource reserves (i.e., natural capital)	The value of known natural resource deposits and assets	Alexeev and Conrad 2009; Apergis and Payne 2014; Brunnschweiler and Bulte 2008; Stijns 2005; *Chapter 2; Chapter 4*
Natural resource production	The volumes of extracted natural resources	Humphrey and Moroney 1975; Leamer 1984
Natural resource rents	The surplus value of natural resource production after subtracting conventional costs	Bond and Fajgenbaum 2014; Bhattacharyya and Hodler 2014; Chauvet and Collier 2008; Collier and Hoeffler 2009; *Chapter 4*
Natural resource exports	The share of the natural resource-sector exports in total exports	Boschini et al. 2013; Mehlum et al. 2006; Neumayer 2004; Sachs and Warner 1995; *Chapter 4; many more*
Government resource revenues	The value of natural resource taxation levied by governments	Lebdioui 2019; *Chapter 4; Chapter 5*.
Share of natural capital (in total capital/ Inclusive Wealth)	The ratio of natural capital (first indicator) to all capital types (i.e., natural + produced + human capital)	Gylfason 2001; Hodler 2006; *Chapter 2; Chapter 3*.

However, criticism of the resource curse's econometric foundations grows as the literature expands. Key variables and concepts are poorly defined and measured and used interchangeably erroneously (Lebdioui 2021). For instance, most cross-country studies consider the intensity of natural resources in exports (i.e., the percentage of natural resource exports in GDP) (see Table 1.2 for references). Others focus on resource rents that approximate production scale (see Table 1.2). Both branches allude to studying resource dependence, yet they measure wildly different things. Indeed, export intensity and production scale can give opposing impressions of natural resource dependence. Norway earns substantially more resource rents than Singapore but has a lower natural resource export intensity and vice versa. A single concept or indicator cannot capture the multidimensionality of resource dependence—or natural resource's relationship with development.

Furthermore, scholars increasingly recognize that the complexity of the relationship between natural resources and development, which can include both negative and positive channels (Stijns 2005). Attempting to bring more conceptual and empirical clarity, Brunnschweiler and Bulte (2008) distinguish between resource dependence and resource abundance. Dependence is a flow variable that reflects the intensity with which an economy draws on natural resources. Abundance is a stock measure indicating the availability of natural resources (i.e., natural capital). Brunnschweiler and Bulte (2008) argue that resource abundance is insufficient to cause a curse. Instead, a resource curse can occur only when countries rely heavily on natural resources without a clear development strategy. However, other studies considering resource abundance sometimes find a positive or no impact on development (Alexeev and Conrad 2009; Herb 2005; Maloney et al. 2002; Stijns 2005). Mixed evidence accumulates and the resource curse is no longer uncontested (see Figure 1.3).

Additionally, endogeneity plagues the literature leading to unreliable empirical outcomes and conclusion (Van der Ploeg and Poelhekke 2017, 2019). The common indicator—resource exports as a percentage of Gross Domestic Product (GDP)—purports to capture how much an economy relies on its natural resource endowments and sector. However, a high value may not indicate dependence. Instead, it could reflect that failed economic policies lead to an underdeveloped industrialized material goods sector, stunting development (Frankel 2010). Similar endogeneity issues apply to other natural resource variables. Thus, it is conceivable that most empirical results are biased. Econometric rigor is needed.

Several methods emerge in the literature to strengthen empirical results. Notably, Brunnschweiler and Bulte's seminal 2008 work applies the instrumental variable approach to address endogeneity.[10] Similarly, researchers increasingly turn to within-country evidence to study the resource curse (Cust and Poelhekke 2015). Identification strategies improve substantially, focusing on the exogeneity of natural resource variables using quasi- and natural experiments and datasets with finer resolutions. The diversity of natural resource indicators and the growing need to address endogeneity pave the way for the present state of resource curse research. Currently, studies yield more compelling evidence of resource curses and blessings (see Cust and Poelhekke 2017 and Manzano and Gutiérrez 2019 for a discussion).

Overall, the resource curse literature has made substantial methodological progress over its extensive history. Better methods and identification approaches make recent findings more robust. However, most studies focus on the short-term economic performance. Yet, this dissertation argues it is imperative to study the effects of natural resource exploitation on intergenerational well-being/sustainable development. The following section discusses the literature on this topic: the resource curse and sustainable development.

1.3.2. The resource curse and sustainable development: An emerging nexus

Although most resource curse literature uses GDP as the primary dependent variable, others move toward so-called beyond-GDP indicators. For instance, the initial estimates for Genuine Savings by Hamilton and Clemens (1999) enable empirical research on the impact of natural resources on sustainable development. Although the authors do not directly regress sustainable development on natural resource extraction, they find the empirical pattern that natural resource-dependent countries operate less sustainably (Hamilton and Clemens, Figure 2, p. 344).

Atkinson and Hamilton (2003) and Neumayer (2004) regress Genuine Savings on natural resources (measured by the troublesome ‘intensity of trade’ variable). They each find a negative correlation supporting the preliminary evidence by Hamilton and Clemens. However, Atkinson and Hamilton and Neumayer both recognize that their empirical analyses are rudimentary.

10. Brunnschweiler and Bulte’s (2008) efforts, in particular, have been questioned for the robustness of their application of instrumental variables (Van der Ploeg and Poelhekke 2010). Nevertheless, their work has set the field's standard for causal identification using cross-country studies.

They urge other researchers to delve further into the relationship by applying sophisticated methods.

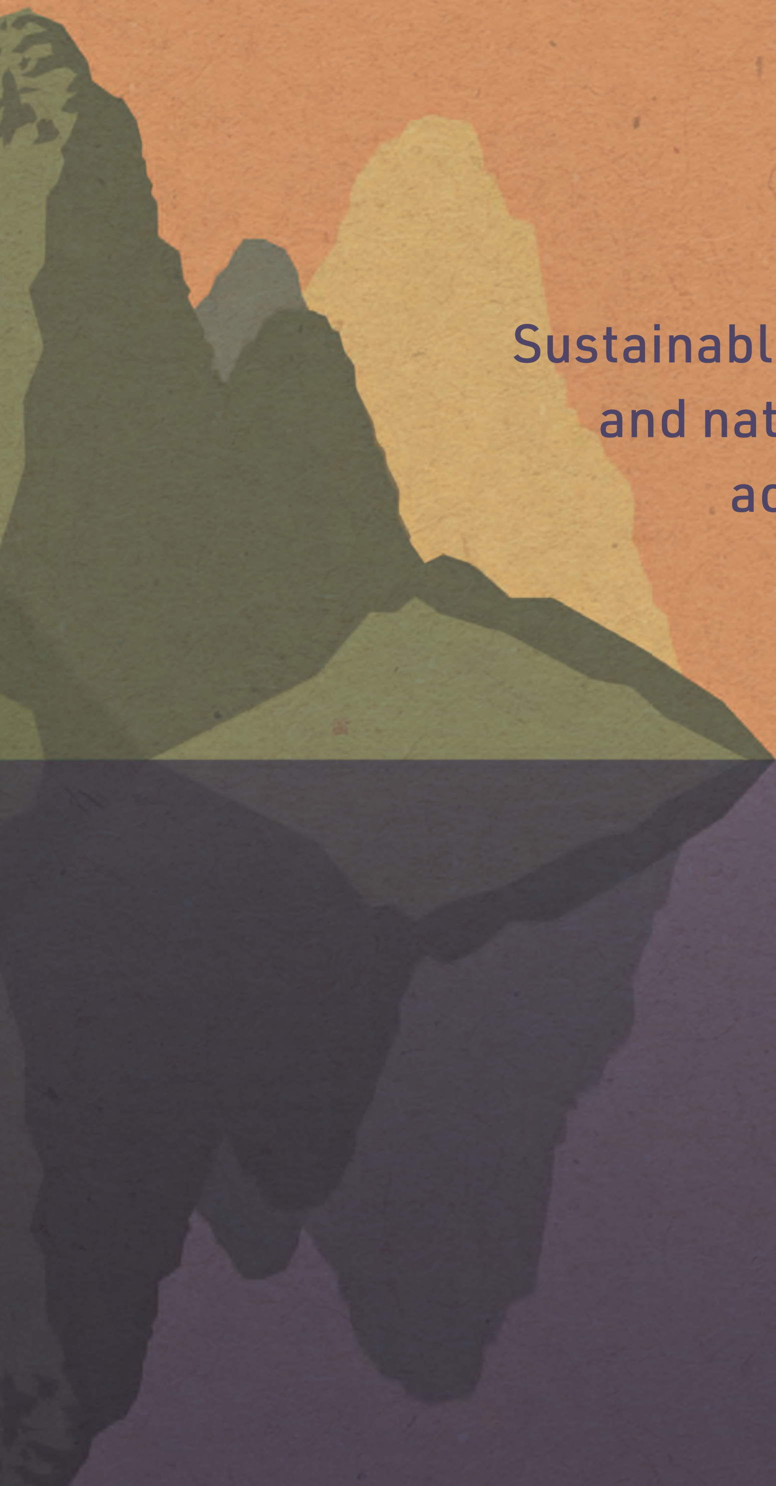
Dietz et al. (2007) are the first to employ econometric techniques to address endogeneity concerns by using an Arellano-Bond panel model.[11] They find a negative relationship, albeit using the narrow 'resource exports' indicator. Since Dietz et al. (2007), no studies apply major methodological innovation to the topic. Ones that examine the relationship between natural resources and sustainable development continue to use either resource trade intensity (Boos and Holm-Müller 2013; Hess 2010; Forson et al. 2017) or natural resource rents (Koirala and Pradhan 2020). However, they neither consider the narrow applicability of their independent variables nor the endogeneity issues.

Here, this dissertation progresses our empirical understanding of the relationship between natural resources and sustainable development, focusing on natural resource conversion. When Van der Ploeg (2011) introduces the theoretical notion of applying the Hartwick rule of natural resource conversion in an economy, he concludes, "Alas, no empirical tests of this proposition are available yet (p. 401)". This still rings true.[12] The studies mentioned earlier do not consider natural capital extraction and instead rely on the narrowly defined 'exports as a percentage of GDP'. Hence, this dissertation advances the literature by studying natural resource conversion more explicitly and comprehensively.

The remainder of this dissertation is organized as follows. Chapter 2 explores the empirical relationship between the three capital stocks and sustainable development. The chapter focuses particularly on whether the sheer presence of natural capital is associated with unsustainable development trajectories. Chapter 3 examines empirically how natural resource depletion relates to sustainable development. Chapter 4 decomposes the process of natural resource conversion to pinpoint the factors that foster and inhibit sustainable development. Chapter 5 exploits exogenous variation in government natural resource revenues, an underutilized measurement of natural resources, to find how government spending contributes to sustainable development.

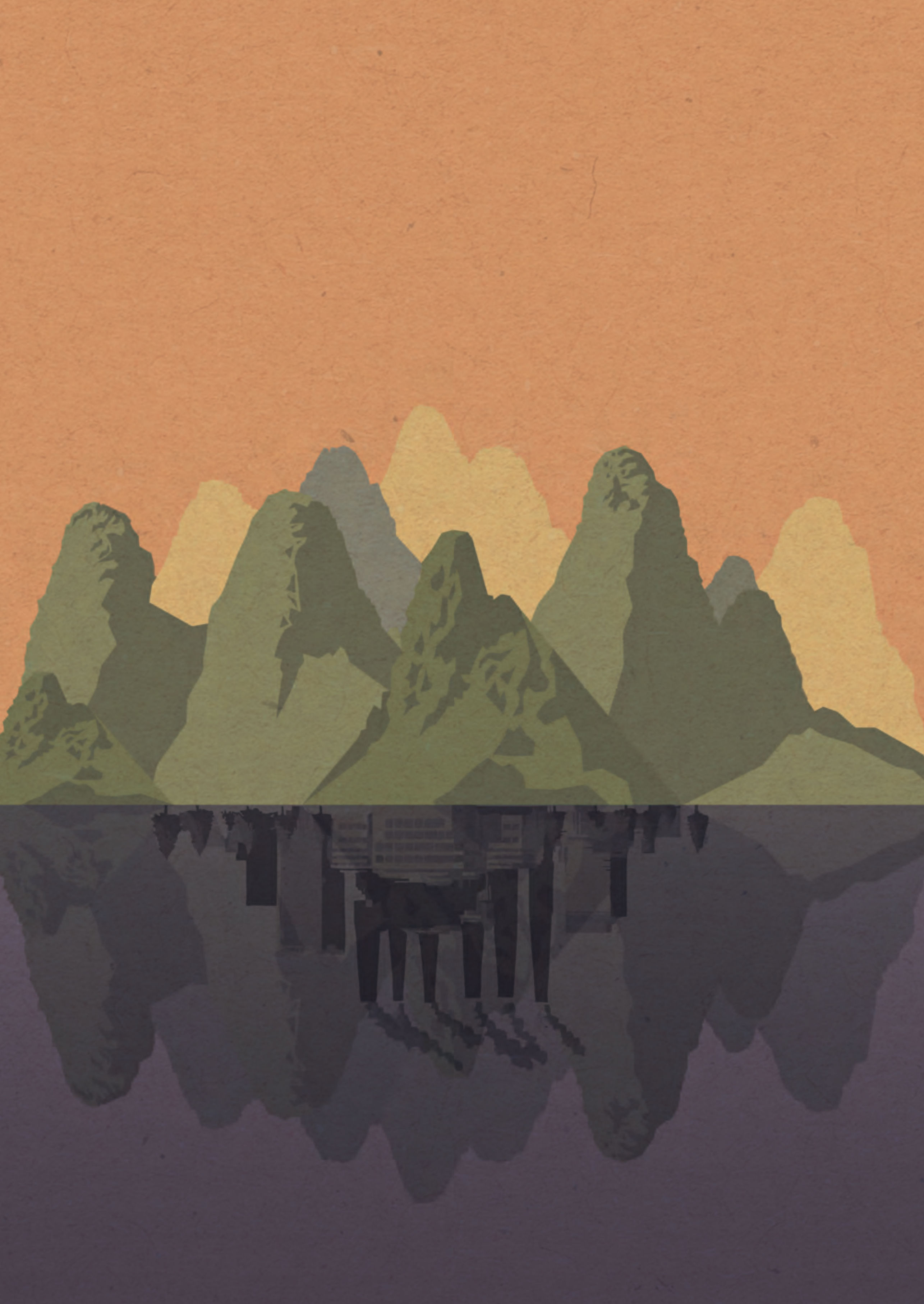
11. Arellano-Bond is a specific dynamic panel model technique that combines first differences and instrumental variables to address endogeneity.

12. Boos and Holm-Müller (2012) discuss theories underlying the relationship between natural capital and sustainable development, but no empirical work considers actual depletion.



Part 1

Sustainable development and natural resources across countries



Chapter 2.

Cross-country convergence of income and Inclusive Wealth: The roles of natural, human, and produced capital

'It is not the increase of consumption or production which makes us rich, but the increase in capital.' - Kenneth Boulding, 1950, p. 79

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Abstract

Recent economic convergence studies show that cross-country income inequalities have declined since the 1990s. However, many economists argue that inclusive wealth, and not income, is the relevant indicator of well-being and satisfaction of preferences. Hence, this chapter analyses the convergence of per capita Inclusive Wealth, which comprises all capital assets that contribute to the production of goods and services and the well-being of its society. Using different techniques for estimating convergence in a sample of 140 countries between 1990 and 2010, the chapter finds that Inclusive Wealth is diverging unconditionally, even though per capita GDP is converging unconditionally. Natural resource-rich countries that lack human capital, in particular, appear unable to keep up with the global per capita Inclusive Wealth growth rate. A trend emerges towards a bimodal global distribution of Inclusive Wealth with a substantial low-wealth peak. Although swift income convergence appears promising for developing nations, I thus caution against optimism. When considering a more appropriate measure of future well-being, such as Inclusive Wealth, the economic outlook for many countries is bleaker than recent economic convergence studies suggest.

2.1. Introduction

The issue of cross-country differentials in development has been of great concern among economists and spawned a deep literature. Based on the work by Solow (1956), many prominent economists suggest that developing countries grow faster than developed ones (e.g., Barro and Sala-i-Martin 1992; Mankiw et al. 1992; Sala-i-Martin 1996). This convergence hypothesis, however, remains a lively debate as innovations bolster the support for convergence and provide evidence against it (Johnson and Papageorgiou 2020). Recent studies claim that poor countries' income have been catching up to the rich since the mid-1990s (Kremer et al. 2022; Patel et al. 2021; Roy et al. 2016). However, there is a growing consensus that (inclusive) wealth matters more than income for welfare (Arrow et al. 2004; Boulding 1950; Clark and Harley 2020; Dasgupta et al. 2021; Stiglitz et al. 2009, p. 29). Scholars agree that income alone is insufficient to approximate welfare (Hoekstra 2019; Jorgenson 2018; Nordhaus and Tobin 1973). Even Simon Kuznets (1934), an architect of national income measures, famously said, 'The welfare of a nation can scarcely be inferred from a measure of national income'.

A prominent critique is that Gross Domestic Product (GDP), a flow variable indicating market dollars of output annually, does not account for the depreciation of capital assets. Perhaps most notably, GDP figures exclude the environmental damage of production. In contrast, Inclusive Wealth—a stock-based measure comprising all capital assets contributing to production and well-being—includes non-market depreciations. Hence, Inclusive Wealth is the relevant indicator for assessing countries' ability to achieve well-being. When a country's per capita Inclusive Wealth grows, the average citizen has more capital assets available to earn income and pursue well-being. As Sir Partha Dasgupta puts it: 'by economic progress we should mean growth in Inclusive Wealth' (2021, p. 5).

Evidence suggests that impressive increases in per capita GDP may come at the expense of the per capita Inclusive Wealth stock in many developing economies. A prime example is Laos (Lao PDR). Laos achieved annual per capita GDP growth of some 6% but a simultaneous annual decline of 1.5% in per capita Inclusive Wealth between 1990 and 2010 (UNU-IHDP-UNEP 2015). Laos's case is not unique. According to the United Nations University, one-third of all countries worldwide experienced a decline in per capita wealth despite achieving income growth in this period. This mismatch between income and wealth highlights a blind spot in convergence research. Income convergence suggests that the economic future is bright for billions of people. However, the ability to achieve well-being erodes when countries liquidate wealth for present-day consumption. An impending divergence of standards of living may be imminent.

This study uses the Inclusive Wealth indicator (UNU-IHDP-UNEP 2015) to investigate cross-country wealth convergence. Inclusive Wealth measures the social value of the productive base comprising stocks of produced, human, and natural capital for 140 countries between 1990 and 2010. The empirical strategy takes several approaches to estimate convergence. First, the chapter tests so-called β-convergence. This idea asserts an inverse relationship between a country's stock of wealth and its growth rate. I distinguish between unconditional or absolute convergence, which excludes structural determinants of development, and conditional convergence, which includes these so-called steady-state properties. The analysis employs a variety of techniques to address cross-sectional dependence and endogeneity. However, β-convergence is not a sufficient condition to bridge the gap in terms of development *levels* (Quah 1993; Young et al. 2008). Therefore, I also analyze σ-convergence and stochastic convergence to understand better the convergence across the Inclusive Wealth cross-country distribution. Finally, I perform Blinder-Oaxaca decomposition, quantile regression, and club convergence analyses to demonstrate intra-distribution dynamics that remain unaccounted for in the previous analyses.

The study provides novel empirical evidence on cross-country convergence. Although the analysis confirms absolute/unconditional convergence of national income, results also reveal that absolute/unconditional divergence of per capita Inclusive Wealth co-occurs. This discrepancy warrants caution against optimism. Many countries appear to earn income at the expense of their income-earning capacity. What empirical evidence I find of conditional Inclusive Wealth convergence comes with caveats. First, the evidence is not robust to bias-corrected estimation techniques that address endogeneity, finding conditional Inclusive Wealth divergence instead of convergence. Second, the speed of supposed conditional wealth convergence is much lower than conditional income convergence, suggesting that GDP convergence overestimates poor countries catching up, if at all. Third, a country's capital stock composition—not its size—accurately predicts cross-country Inclusive Wealth convergence dynamics. Human and natural abundance drive divergence, hampering countries at the center of the per capita wealth distribution. The Inclusive Wealth distribution is gradually becoming more dispersed with a more voluminous low-wealth club.

The remainder of this chapter is organized as follows. Section 2.2 reviews the literature on cross-country convergence using non-income-based indicators. Section 2.3 provides a conceptual background on the relationships among Inclusive Wealth, income, and welfare. Section 2.4 describes the methodology and data. Section 2.5 presents and discusses the results of the analysis. Finally, Section 2.6 concludes.

2.2. Literature review: 'Beyond-GDP' metrics and convergence

Aside from GDP, cross-country convergence studies employ composite indicators and sets of non-income-based variables to measure well-being. I briefly review the main findings of this literature.

In general, the result is that countries are converging slowly. Most studies employ the Human Development Index, which aggregates three categories—income, health, and education—into a 0 to 1 measure. Noorbakhsh's (2006) pioneering study tests β- and σ-convergence of HDI between 1975 and 2004 among 93 developing countries, finding that gaps decrease. Subsequent studies show that the speed of HDI convergence is "agonizingly slow" (Konya and Guisan 2008), the income dimension is unrelated to education and health convergence (Gray Molina and Purser 2010), and HDI convergence is not a smooth process (Mayer-Foulkes 2010). More recently, Jordá and Sarabia's (2015) sophisticated convergence techniques corroborate all previous findings, firmly establishing the convergence of HDI and its components. Additionally, Ortega et al.'s (2016) heterogeneity analysis finds that not all countries converge toward the same final state but show patterns of club convergence.

The consistent findings of HDI convergence observed across diverse samples and employing various convergence techniques indicate a pervasive trend of well-being convergence among different countries. However, HDI alone is ill-equipped to handle the complexity of measuring human well-being. The indicator is criticized for its arbitrary design, equal weights and substitutability of components, as well as variable selection, among other things (Kovacevic 2010). Fortunately, the literature employs several alternative indicators of well-being.

Other studies examine cross-country convergence using a set of disaggregated quality-of-life variables or composite indices that consider more dimensions than income, education, and health. For example, Neumayer (2003) uses a wide range of quality-of-life variables to study β- and σ-convergence between 1960 and 1999 for a large panel of countries. His findings indicate a general trend of convergence, attributed partially to upper/lower bounds on some variables (e.g., infant mortality, literacy). Nevertheless, there is convergence across the board; as he puts it: "convergence big-time". Kenny (2005) confirms this pattern, finding quality-of-life convergence even in decades when GDP did not converge.

Similarly, Peiro-Palomino et al. (2023) and Gligorić Matić et al. (2020) find cross-country convergence using the Social Progress Index and Legatum Prosperity Index, which draw on dozens and hundreds of variables, respectively. Sinha Babu and Datta (2016) find convergence using four sustainable development indicators. There is even well-being convergence at the individual level. Ram (2021) estimates β- and σ-convergence of happiness across 132 countries from 2005 to 2018, while Apergis and Georgellis (2015) and Guriev and Melnikov find happiness convergence in smaller samples. The only limitation is the unequal distribution of quality-of-life convergence across countries (Giannas et al. 1999; Paprotny 2021).

Thus, on close examination, well-being convergence is strikingly uniform across samples spanning a century, an array of estimation techniques, scopes, and indicators. Collectively, the evidence portrays a favorable historical development.

What have we yet to uncover about 'beyond-GDP' convergence? Most studies use retrospective indicators of well-being. They implicitly explore the question, How have historical inequalities evolved?. However, from a development standpoint, there is an opportunity to embark on a prospective analysis: How are inequalities likely to evolve?. The Inclusive Wealth indicator is well-suited to address this question. Unlike estimations of present-day quality-of-life, this indicator monitors societies' capacity to achieve well-being and approximates a country's income-earning potential.

Thus, Inclusive Wealth can offer valuable insights into the potential for well-being and income. Nevertheless, convergence studies employing prospective indicators remain scarce. This study endeavors to bridge this gap by examining cross-country Inclusive Wealth convergence.

2.3. Conceptualizing income, wealth, and well-being

As an alternative to Gross Domestic Product (GDP), some researchers consider Inclusive Wealth the preferred measure of economic progress (e.g., Dasgupta 2021). There is a growing consensus that Inclusive Wealth is vital to understanding human's ability to flourish (Arrow et al. 2004; Dasgupta et al. 2021; Stiglitz et al. 2009). Its design aims to encompass the material means to support human well-being (Polasky et al. 2015; van den Bergh 2021). Wealth aggregates the value of all capital assets (i.e., produced, human, and natural) that contribute to the welfare of society (Dasgupta 2014; Hamilton and Hepburn

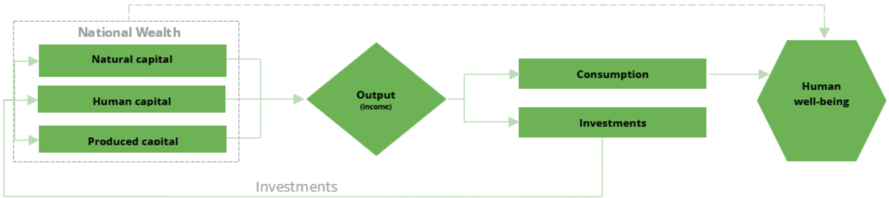

Figure 2.1. Wealth creation and its contribution to welfare in the capital-driven economy
Notes: This figure illustrates a stylized model of wealth creation. The productive base comprising natural, human, and produced capital creates output for consumption and reinvestment. Wealth also contributes to well-being directly. The illustration combines elements from two figures from the Inclusive Wealth Report (UNU-IHDP-UNEP 2015, p. 18 and p. 203).

Figure 2.1 illustrates the links between wealth and well-being in a stylized economy. Wealth is the stock of produced, human, and natural capital assets that supply flows of resource inputs for production. In turn, the resulting output (income) is either reinvested to form new capital or used to satisfy present-day needs. Ideally, income contributes sufficiently to capital accumulation. When wealth grows, future generations have more resources and, therefore, an improved ability to earn income and raise their standard of living.

Nevertheless, some economies accumulate wealth insufficiently and consume too much (Arrow et al. 2004). Instead of building capital assets, these countries liquidate assets to earn income. This matters for economic convergence because such a strategy is unsustainable in the long run. Consider Nauru, a country with the highest per capita GDP in the world at some point in the 1970s. This island nation has since exhausted its phosphate deposits and destroyed its agricultural potential. The island nation now ranks among the world's poorest in per capita GDP. Nauru's economic collapse signals that impressive income stats are merely transitory when driven by capital depletion. By extension, income convergence will not last when fueled by capital consumption. A decline in one type of capital asset can only contribute to 'catch-up development' when its revenues are converted sufficiently into other forms of wealth with equal or greater social value.[1] Hence, studying wealth convergence offers context to the existing literature on income convergence. Where income flows can gauge well-being today, wealth is a prospective measure of welfare—showing how income flows may develop in the future.

Some consider Inclusive Wealth and income complementary measures of economic performance (World Bank 2021).[2] Like the balance sheet and income statement provide complementary information on firm performance, a country's national accounts are more comprehensive with both income flows and stock values of its assets. The rationale is that wealth alone cannot account for well-being. Consumption of goods and services (e.g., food, clothes) requires income flows. Without income, the stocks of natural, produced, and human capital assets can only provide for a limited array of material needs. As Stiglitz and Sen (2009, p. 29) put it, 'income is an important gauge for standards of living, but in the end consumption and consumption possibilities over time matter. The time dimension brings in wealth.'

2.4. Data and method

2.4.1. Data

2.4.1.1. Dependent variables

The first dependent variable is per capita Inclusive Wealth provided by the Inclusive Wealth Report's data appendix (UNU-IHDP-UNEP 2015). Inclusive Wealth is developed by the United Nations Environment Program and the United Nations University—International Human Dimensions Program to measure a nation's capability to earn income and achieve well-being (Harley and Clark 2020). As a forward-looking measure of development, it approximate whether a society can draw on its resources indefinitely to sustain its current level of development

1. The Inclusive Wealth framework assumes perfect substitutability between all capital types. It does not account for the damages from liquidating excessively one kind of capital asset (e.g., biodiversity loss, irreversible climate change, threshold effects).
2. Meanwhile, some reject income as a measure of well-being. For instance, even the System of National Accounts discourages GDP as a measure of welfare.

(Dasgupta et al. 2021). As such, Inclusive Wealth addresses several shortcomings of income-based measures of prosperity (Polasky et al. 2015).

Inclusive Wealth is defined as the aggregate value of all capital assets. Each capital stock is calculated by aggregating the value of a list of assets, each reflecting the asset's lifetime potential to generate income. Shadow prices, which assign weights to each capital type, are constant within the period (UNU-IHDP-UNEP 2015, p. 19).[3] For instance, the value of a particular natural resource is usually the average market value of one unit of natural capital over the years 1990–2008. Therefore, the real dollar values of each capital stock are determined by its biophysical volume and are insensitive to price fluctuations. The original data provides values of each capital stock for 140 countries at five moments in time (1990, 1995, 2000, 2005, and 2010). Together, these countries cover 95% of the world's population.

The second dependent variable, per capita GDP, serves as a benchmark. The purpose is to juxtapose Inclusive Wealth convergence, which is unstudied, with the standard indicator for economic convergence. I employ the Penn World Table (PWT 10.1) 'real GDP at constant 2017 prices' data (Feenstra et al. 2015).

Furthermore, some analyses operationalize the dependent variable Inclusive Wealth as the change relative to the global mean by standardizing the natural log of per capita Inclusive Wealth per period (see Section 2.4.2.3).[4] To clarify, consider Figure 2.2, which depicts the cross-country Inclusive Wealth distribution in 1990. The left y-axis shows the estimated kernel density distribution of per capita Inclusive Wealth. The right y-axis displays this dependent variable: countries' change within the distribution between 1990 and 2010. A negative (positive) value shows a movement to the left (right) in the distribution.

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3. This is an important property of the data. The World Bank's *Changing Wealth of Nations Report* (2021) provides alternative measurements of wealth. However, it assigns time-fluctuating values to capital assets. As a result, an increase in the wealth of a nation in the World Bank's approach may indicate asset appreciation even though the biophysical stock of assets has declined. This applies to many natural capital-dependent countries, where overexploitation can seem sustainable. The data is immune to this misestimation.
4. The mean value is therefore equal to 0. A country may exhibit positive per capita wealth growth below the global average, thus showing a negative value for this variable (e.g., Brazil, Switzerland). Especially oil-states (Qatar, United Arab Emirates, Iraq) significantly deteriorate relative wealth (-0.6). Similarly, top performers improved by up to 0.45 standard deviations (China, South Korea, Maldives)

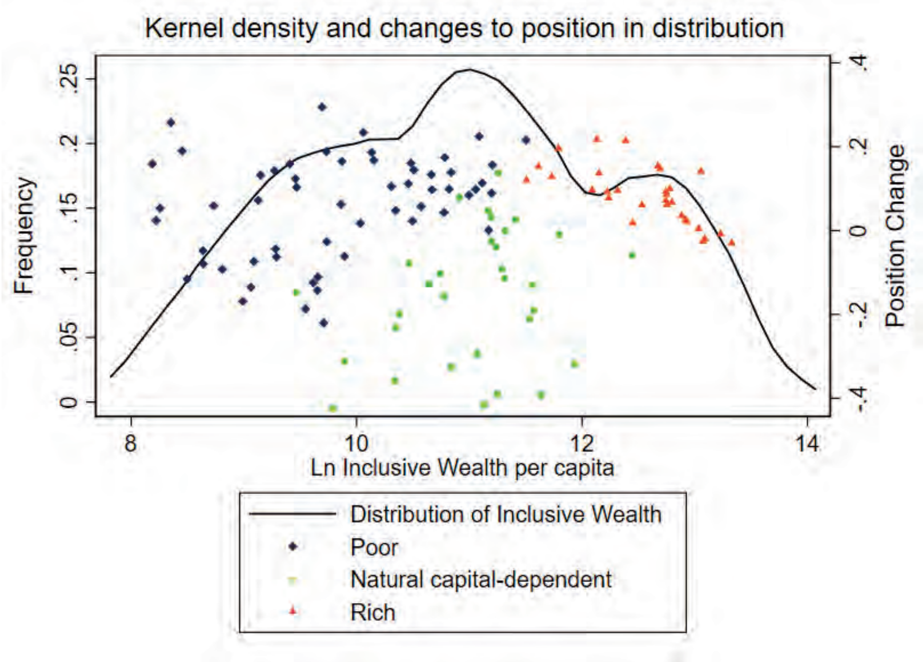

Figure 2.2. Cross-country wealth distribution and relative country performance

Notes: The table presents a kernel density plot based on the 1990 values of per capita Inclusive Wealth (ln) Each mark indicates a country. The left y-axis displays density, and the right y-axis presents countries' change of position in the distribution between 1990 and 2010. Blue diamonds denote poor countries, natural capital-dependent countries are green circles, and rich countries are red triangles. Appendix 2A discusses the method for country categorization.

2.4.1.2. Independent variables

Although convergence analyses typically use a lagged dependent variable as the main independent variable, some analyses in the chapter decompose Inclusive Wealth. Then, the independent variables are the natural logarithms of per capita human, produced, and natural capital. The rationale is that the individual capital stocks provide the inputs to create the goods and services, generating income flows that finance investments in Inclusive Wealth (see Figure 2.1).

Human capital is the largest capital stock, followed by produced and natural capital. Natural capital shows the most cross-country variation. Oil states have the highest values, followed by well-endowed countries with low population density, such as Australia, Canada, and Iceland.

Table 2.1. Descriptive statistics for selected variables

	Mean	Std. dev.	Max.	Min.	N	Notes
Dependent variables						
Inclusive Wealth	10.9	1.43	13.8	8.10	700	Natural log per capita
GDP	11.3	1.94	16.6	6.38	685	Natural log per capita
Independent variables						
Human capital	10.1	1.61	12.9	6.96	700	Natural log per capita
Produced capital	9.03	1.75	12.3	4.20	700	Natural log per capita
Natural capital	8.81	1.86	13.5	1.95	700	Natural log per capita
Steady state control variables						
Population density in 1500 CE	7.02	10.3	62.5	0.022	690	
Positive crops for plow	0.515	0.403	0.998	0	685	Scale 0 to 1
Distance from the regional frontier in 1500 CE	7.31	1.62	9.29	0	700	Log (1 + distance)
Predicted genetic diversity	0.706	0.054	0.767	0.572	700	Scale 0 to 1
Domesticable animals	4.02	4.12	9	0	490	Absolute number of species
Neolithic transition timing	8.31	0.644	9.26	5.89	685	Log
Years before agriculture	5.47	2.06	10.4	1.4	680	Weighted, see Putterman and Weil (2010)
Population in 1000 CE	12.6	2.03	18.0	5.94	670	Log

Notes: The table reports all data used in the main analyses and provides values for all countries in the sample (140) at each moment, totaling 700 maximum observations (unless indicated otherwise).

Natural capital consists of renewable and non-renewable resources. Some countries' non-renewable resource data are missing in the Inclusive Wealth report (e.g., Sierra Leone, Uganda, Rwanda, The Gambia). Depleting and reinvesting unreported mineral resources may give a false positive indication of Inclusive Wealth, leading to an amplification bias. A dummy addresses the issue.

2.4.1.2.3. Control variables

Analyses of conditional convergence employ steady state control variables that measure sources of lasting development differentials across countries. Many consider the differences between steady states as permanent and deeply rooted in countries' institutions, culture, and geography. However, Kremer et al. (2022) show that the traditional set of steady state control variables is not permanent but is itself converging.[5] Therefore, I instead utilize so-called *deep determinants*. This category of variables comprises hundreds or thousands of years old (time-invariant) factors determining today's development rates. The analysis includes population density in the year 1500 CE and the population in 1000 CE (Putterman and Weil 2010; Comin et al. 2010), the presence of positive crops for the plow (Alesina et al. 2013), a head start in the state of technology in 1500 CE (i.e., distance to regional frontier), genetic diversity (Ashraf and Galore 2013), the number of domesticable animals (Diamond 2002), and the timing of the neolithic transition from hunter-gatherer to an agricultural society (Ashraf and Galore 2013).[6] Details on all variables appear in Table 2.1; detailed information on the main variables is found in Appendix 2B.

2.4.2. Empirical models

2.4.2.1. Parametric convergence analyses

The baseline analysis follows Barro and Sala-i-Martin's (1992) OLS regression approach to study β-convergence. The dependent variable is the annualized log change in per capita Inclusive Wealth over a 5-year interval. Employing initial per capita Inclusive Wealth as the independent variable, I conduct regression analyses with two distinct specifications of this method. The first excludes the vector of steady state control variables, indicating unconditional/absolute β-convergence, while the second includes the control variables, representing conditional β-convergence. Equation 2.1 describes the estimations:

$$\frac{\ln IW_{t+5} - \ln IW_t}{T} = \alpha + \beta_1 \cdot \ln IW_{\mathrm{it}} + [X_{\mathrm{it}}] + T_t + \varepsilon_{it} \qquad \text{(Eq 2.1)}$$

where *IW* denotes per capita Inclusive Wealth and *X* the vector of steady-state controls for country *i* at time *t*.

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5. To be complete, we have used Kremer's set of control variables, which do a worse job of explaining cross-country variation in Inclusive Wealth growth rates, and an equal job at explaining GDP growth rates. See Appendix 2C.
6. The number of variables is selected based on parsimony and model fit.

I expand the baseline regression of conditional and unconditional convergence by accounting for cross-sectional dependence. Spatial autocorrelation, which is the tendency of spatially proximate countries to be more similar due to regional clustering and spillover effects (Ertur and Koch 2007), causes cross-sectional dependence. Appendix 2D reveals significant spatial autocorrelation of Inclusive Wealth and GDP. Consequently, I use a Spatial Autoregressive Regression (SAR) estimation to model that spatial dependence. It introduces a spatial lag that measures spatial effects, rendering the coefficient for β-convergence more efficient. The model is tested with and without country-fixed effects (Lee and Yu 2010).[7] The fixed effects account for all unobserved time-invariant determinants of the Inclusive Wealth growth rate, including the steady-state properties. Equation 2.2 describes the model:

$$\frac{\ln IW_{t+5} - \ln IW_t}{T} = [a_i] + \lambda MIW_{it} + \beta_1 \cdot \ln IW_{\mathrm{it}} + [X_{\mathrm{it}}] + T_t + u_{it} \qquad \text{(Eq 2.2)}$$

where *IW* is per capita Inclusive Wealth for country *i* at time *t*. X_{it} is a vector of steady state control variables for the estimation without fixed effects, and T_t is the year fixed effects. *M* is the spatial weight matrix calculated using inverse distances between all countries. λ indicates the spatial lag of the dependent variable *IW*. Appendix 2F presents a sensitivity analysis that uses a contiguity spatial weight matrix in which only neighboring countries are spatially dependent.

I repeat the standard OLS and SAR methods with the natural log of per capita GDP as dependent and independent variables. Furthermore, I decompose the Inclusive Wealth analysis by considering human, produced, and natural capital as independent variables. Doing so targets the sources of convergence/divergence in the baseline regressions.

2.4.2.2. Non-parametric convergence analyses

Next, I estimate σ-convergence and stochastic convergence. Although cross-country convergence of growth rates (β-convergence) would suggest the catching up of poor countries, it is not a certainty (Quah 1996; Young et al. 2008). Development gaps may even persist despite a robust inverse relationship between the level of economic prosperity and its growth rate. Relying solely on evidence of β-convergence is inadequate for inferring

7. When considering fixed effects, the resulting dynamic fixed effects model produces a downward bias (Nickell 1981). As a robustness check, Appendix 2E considers a bootstrap-based bias-corrected fixed effects model to address this source of endogeneity.

convergence across the distribution of wealth. Conversely, σ-convergence examines the statistical dispersion of that distribution and considers Inclusive Wealth levels. I estimate the σ for the natural log of per capita Inclusive Wealth, as shown by equation (Eq 2.3):[8]

$$\sigma = \left[\left(\frac{1}{n}\right)\sum\left(lnIW_{it} - \overline{lnIW_t}\right)^2\right]^{0.5} \qquad \text{(Eq 2.3)}$$

I calculate the σ per period. Its decrease indicates that the per capita Inclusive Wealth distribution is becoming less dispersed (i.e., convergence). Conversely, an increase indicates a divergence of cross-country per capita Inclusive Wealth.

Additionally, I conduct panel unit root tests to estimate stochastic convergence. Stochastic convergence differs from σ-convergence by evaluating the time series of individual countries, as opposed to dispersion across the panel. The test also considers level effects to find whether cross-country differences in per capita Inclusive Wealth are persistent. Panel unit root tests assess the stationarity of countries' time series. Stationarity implies reversion to a common mean (i.e., convergence). It means neither idiosyncratic country-specific factors nor shocks can explain long run Inclusive Wealth growth.

I use the Pesaran (IPS) (2007) and Fisher test (Choi 2001) to assess stochastic convergence. The IPS approach is more dependable than the standard Levin-Li-Chu (LLC) approach because it handles cross-sectional dependence (implied by spatial autocorrelation), small samples, and heteroskedasticity. The Fisher test shares these properties while also dealing with serial correlation better. In the IPS and Fisher test, the null hypothesis is non-stationarity (i.e., no convergence), and the alternative hypothesis indicates that at least one country has a stationary time series. As such, stochastic convergence methods do not show how many countries converge or at what speed.

2.4.2.3. Estimation heterogeneity of convergence

Next, the study examines its intra-distribution dynamics to understand the convergence mechanisms better. I perform a Blinder-Oaxaca Decomposition analysis (Blinder 1973; Oaxaca 1973), which takes the difference in the

8. Other studies opt for the coefficient of variation (CV), which divides σ by the panel mean each year. This method is more useful when the mean changes substantially over time. In our sample, the mean moves very slowly, meaning no substantive difference exist between using σ and CV.

estimated coefficient of the dependent variable between two groups and attributes the difference to a vector of explanatory variables. The analysis compares changes in position in the cross-country wealth distribution (dependent variable) between groups. Then, it shows how capital stocks and steady state control variables explain the difference in performance between groups. A counterfactual calculates the unexplained component. This element indicates what part of convergence or divergence is unaccounted for by the explanatory variables.

An essential condition is that the selection of units within groups is exogenous. The analysis would violate the independent selection assumption when comparing groups based on per capita Inclusive Wealth. Instead, group selection is based on the wealth composition. Using Ahmad et al.'s (2018) categorization (see Appendix 2A), there are three types of countries: poor, rich, and natural capital-dependent. The color and symbol combinations in Figure 2.2 display each country's position in the distribution and change thereof and denote country type. I compare natural capital-dependent countries to rich countries and poor countries. A direct comparison between rich and poor would violate the independent selection assumption. The analysis reports robust standard errors and pools the groups.

Furthermore, I perform a quantile regression analysis to investigate variations in the drivers of convergence and divergence across different points of the wealth distribution. The analysis shows how explanatory variables affect top- and worst-performing countries differently. The dependent variable of the approach is countries' change in position in the wealth distribution. Results show the 0.1^{st}, 0.25^{th}, 0.5^{th}, 0.75^{th}, and 0.9^{th} quantile, where 0.1^{st} refers to the worst-performing countries and 0.9^{th} to the top-performing. The latter are not necessarily the wealthiest.

Finally, I test for club convergence following the standard approach by Phillips and Sul (2007, 2009). Club convergence refers to the idea that there need not be a single universal convergence pattern. Instead, groups of countries with similar characteristics converge in economic performance, leading to clusters of countries (i.e., 'clubs'). Hence, countries within clubs may converge, while the clubs themselves could diverge. The Phillips and Sul (2007) provide the current standard convergence club algorithm. The econometrics behind the algorithm is too extensive for this section. The original authors' work and Tomal (2023) discuss the econometrics in more detail.

2.5. Results

2.5.1. Parametric techniques: β-convergence analyses

2.5.1.1. β-convergence of GDP

I first test β-convergence of per capita GDP growth before considering the primary dependent variable (per capita Inclusive Wealth). I perform the standard unconditional and conditional convergence estimation (Equation 2.1). Table 2.2 presents the results.

Results show that the initial level of per capita GDP is negatively associated with per capita GDP growth, which is evidence of β-convergence of income. Resonating with recent evidence, the analyses confirm unconditional (Model 1) and conditional income convergence (Model 2) since the 1990s using the standard OLS approach. Including a spatial lag that addresses cross-sectional dependence (Models 3 and 4) greatly improves the models' fit and renders the convergence coefficient more reliable. Hence, (conditional) convergence of per capita GDP appears robust. Model 5 adds country-fixed effects, which absorb all observed and unobserved time-invariant steady state variables. The coefficient for per capita GDP is substantially lower than other models, likely due to the inherent downward bias caused by endogeneity in dynamic fixed effects models (Nickell 1981). Appendix 2E presents a bootstrap-based bias-corrected fixed effects estimate, which addresses the Nickell-type bias and cross-sectional dependence without a spatial lag. The results find conditional GDP convergence, albeit with weaker statistical significance.

A caveat is that the models in Table 2.2 have low explanatory power and many insignificant steady state variables. The difference in R^2 between Models 1 and 2 indicates that the steady state control variables do not explain much variation in GDP growth. To be complete, the sensitivity analysis in Appendix 2C considers an alternative set of control variables for conditional GDP convergence used by Kremer et al. (2022).[9] The results find a similar β-coefficient (-0.025). Although the alternative specification contains some statistically significant steady state variables at the 5% and 10% levels, the explanatory power remains comparable to the original specification. However,

9. Specifically, the alternative set of steady state controls includes population growth, credit to financial institutions, years of schooling, government investment (% GDP) and gross capital formation from the World Development Indicators, as well as Polity2 score (Polity V), civil liberties score, and political rights scores (Freedom House).

the number of statistically significant control variables matches Kremer et al.'s specifications. Therefore, I conclude that conditional convergence of GDP is present between 1990 and 2010, albeit with low explanatory power.

2.5.1.2. β-convergence of Inclusive Wealth

Table 2.3 presents the main results of the β-convergence estimation, reporting how per capita Inclusive Wealth growth is related to a country's level of per capita wealth. The main coefficient in Model 6 is positive, indicating unconditional Inclusive Wealth divergence. The findings imply that countries diverge in Inclusive Wealth despite income convergence for 95% of the population. Given that Inclusive Wealth forms the productive base used to earn future income, it suggests that countries' earning-capacity is drifting apart. Interestingly, this happens at the same rate of income convergence.

Models 7 and 9 invoke steady state control variables excluding and including a spatial lag of the dependent variable, respectively. The analyses find conditional convergence of per capita Inclusive Wealth at half the speed of conditional GDP convergence. Model (10) includes country-fixed effects and a spatial lag, finding conditional Inclusive Wealth convergence. However, as before, these dynamic panel estimates are likely biased downward due to endogeneity. The bias-corrected fixed effects estimates (Table E1, Appendix 2E) indicate that conditional Inclusive Wealth convergence is not robust. Instead, the results suggest conditional *divergence*. The coefficient is substantially larger than 1, rendering conditional divergence of Inclusive Wealth plausible. Overall, the results suggest that developing countries are unlikely to catch up to richer ones when considering Inclusive Wealth as the measure of economic progress.

Compared to the GDP estimates in Table 2.2, the explanatory power of the conditional convergence models for Inclusive Wealth (Table 2.3) is substantially higher. The steady state control variables explain more cross-country variation, indicating that the standard growth specification predicts Inclusive Wealth growth better than its GDP growth. The Pseudo R^2 of 0.551 is quite high for a small sample (N=91), considering the inherent measurement error of Inclusive Wealth and the noise inherent to cross-country studies.

Table 2.2. Baseline results: β-convergence estimations for per capita Gross Domestic Product growth

	Dependent variable:				
	OLS (1)	**OLS (2)**	**SAR-OLS (3)**	**SAR-OLS (4)**	**SAR-FE (5)**
Independent variables					
Gross Domestic Product (natural log)	-0.0019 (0.0011) [p=0.070]	-0.0041 (0.0013) [p=0.001]	-0.0022 (0.00094) [p=0.017]	-0.0053 (0.0015) [p=0.000]	-0.15 (0.0076) [p=0.000]
Control variables					
Population density in 1500		-0.00015 (0.00018) [p=0.416]		-0.000036 (0.00016) [p=0.824]	N/A
Timing of the use of plough		-0.010 (0.0060) [p=0.092]		-0.0077 (0.0071) [p=0.275]	N/A
Distance from the technological frontier in 1500 (natural log)		0.00022 (0.00066) [p=0.739]		-0.00034 (0.00098) [p=0.732]	N/A
Predicted genetic diversity		-0.019 (0.028) [p=0.503]		0.070 (0.052) [p=0.179]	N/A
Number of domesticable animals		0.00035 (0.00088) [p=0.689]		-0.00035 (0.00096) [p=0.713]	N/A
Neolithic transition timing (natural log)		-0.0075 (0.0072) [p=0.298]		-0.0065 (0.0075) [p=0.390]	N/A
Ancestry-adjusted years since agriculture (in thousands)		0.0032 (0.0016) [p=0.043]		0.0043 (0.0019) [p=0.021]	N/A
Population in 1000 (natural log)		0.0048 (0.0013) [p=0.000]		0.0038 (0.0016) [p=0.016]	N/A
Time fixed effects	Y	Y	N/A	N/A	Y
Spatial lag of the dependent variable			-0.34 (0.26) [p=0.194]	-0.90 (0.32) [p=0.005]	0.26 (0.14) [p=0.059]

Table 2.2. Continued

	Dependent variable:				
	OLS (1)	**OLS (2)**	**SAR-OLS (3)**	**SAR-OLS (4)**	**SAR-FE (5)**
N	548	360	137	90	548
#-countries	137	90	137	90	137
(Pseudo) R^2	0.090	0.109	0.256	0.299	N/A

Notes: The table reports a standard OLS log-linear model to test β-convergence in annual Gross Domestic Product per capita growth rates, conditionally and unconditionally. Standard errors are in parentheses. P-values are in square brackets. The standard OLS models (1) and (2) cluster standard errors at the country level. The number of observations for the conditional β convergence estimations in models (2) and (4) are lower due to missing control variable data. The spatial autoregressive model (SAR) with OLS does not allow repeated unit observations. Therefore, it considers one period of twenty years instead of four periods of five years. This reduces the number of observations and omits the time-fixed effects. The SAR fixed effects (FE) model contains no (time-invariant) control variables due to collinearity with the country-fixed effects. The SAR models use an inverse distance spatial weight matrix. The results using a contingency spatial weight matrix are presented in Appendix 2F. The sample comprises 137 countries without steady-state control variables and 90 with steady-state control variables.

Table 2.3. Baseline results: β-convergence estimations for per capita Inclusive Wealth growth

	Dependent variable:				
	OLS (6)	**OLS (7)**	**SAR-OLS (8)**	**SAR-OLS (9)**	**SAR-FE (10)**
Independent variables					
Inclusive Wealth (natural log)	0.0019 (0.00046) [p=0.000]	-0.0022 (0.00054) [p=0.000]	-0.00058 (0.00076) [p=0.448]	-0.0028 (0.00095) [p=0.003]	-0.015 (0.0040) [p=0.000]
Control variables					
Population density in 1500		0.00027 (0.000048) [p=0.000]		0.00025 (0.000093) [p=0.007]	N/A
Timing of the use of plough		0.0066 (0.0026) [p=0.013]		0.0066 (0.0041) [p=0.112]	N/A
Distance from the technological frontier in 1500 (natural log)		-0.0011 (0.00028) [p=0.000]		-0.0011 (0.00054) [p=0.042]	N/A
Predicted genetic diversity		-0.052 (0.013) [p=0.000]		-0.053 (0.021) [p=0.012]	N/A
Number of domesticable animals		0.0017 (0.00032) [p=0.000]		0.0015 (0.00054) [p=0.004]	N/A
Neolithic transition timing (natural log)		-0.0088 (0.0022) [p=0.000]		-0.0086 (0.0041) [p=0.038]	N/A
Ancestry-adjusted years since agriculture (in thousands)		0.014 (0.0058) [p=0.015]		0.013 (0.010) [p=0.221]	N/A
Population in 1000 (natural log)		-0.00098 (0.00040) [p=0.015]		-0.00090 (0.00074) [p=0.224]	N/A
Time fixed effects	Y	Y	N/A	N/A	Y
Missing natural capital dummy	Y	Y	Y	Y	Y
Spatial lag of the dependent variable			1.86 (0.31) [p=0.000]	0.36 (0.48) [p=0.445]	0.60 (0.17) [p=0.000]

Table 2.3. Continued

	Dependent variable:				
	OLS (6)	**OLS (7)**	**SAR-OLS (8)**	**SAR-OLS (9)**	**SAR-FE (10)**
N	560	364	140	91	560
#-countries	140	91	140	91	140
(Pseudo) R^2	0.056	0.479	0.071	0.551	

Notes: The table reports a standard OLS log-linear model to test β-convergence in annual growth rates of per capita Inclusive Wealth, conditionally and unconditionally. Standard errors are in parentheses. P-values are in square brackets. The standard OLS models (6) and (7) cluster standard errors at the country level. The number of observations for the conditional β convergence estimations in models (7) and (9) is lower due to missing control variable data. The spatial autoregressive model (SAR) with OLS does not allow repeated unit observations. Therefore, it considers one period of twenty years instead of four periods of five years. This reduces the number of observations and omits the time-fixed effects. The SAR fixed effects (FE) model contains no (time-invariant) control variables due to collinearity with the country-fixed effects. The SAR models use an inverse distance spatial weight matrix. The results using a contingency spatial weight matrix are presented in Appendix 2F. The sample comprises 140 countries without steady-state control variables and 91 countries with steady-state control variables.

Table 2.4. Decomposed results: β-convergence estimations for per capita Inclusive Wealth growth

	Dependent variable:				
	OLS (11)	**OLS (12)**	**SAR-OLS (13)**	**SAR-OLS (14)**	**SAR-FE (15)**
Independent variables					
Human capital (natural log)	0.0052 (0.00078) [p=0.000]	0.0038 (0.00071) [p=0.000]	0.0064 (0.0011) [p=0.000]	0.0049 (0.0011) [p=0.000]	-0.056 (0.010) [p=0.000]
Produced capital (natural log)	-0.00024 (0.00072) [p=0.736]	0.00060 (0.00073) [p=0.411]	-0.0023 (0.0010) [p=0.027]	-0.00023 (0.0011) [p=0.834]	0.00050 (0.0020) [p=0.801]
Natural capital (natural log)	-0.0043 (0.00035) [p=0.000]	-0.0049 (0.00038) [p=0.000]	-0.0040 (0.00038) [p=0.000]	-0.0048 (0.00050) [p=0.000]	-0.010 (0.0029) [p=0.000]
Control variables					
Population density in 1500		-0.00015 (0.000047) [p=0.001]		-0.00014 (0.000070) [p=0.045]	N/A
Timing of the use of plough		-0.0016 (0.0019) [p=0.412]		-0.00096 (0.0028) [p=0.733]	N/A
Distance from the technological frontier in 1500 (natural log)		-0.000032 (0.00028) [p=0.909]		-0.00014 (0.00036) [p=0.710]	N/A
Predicted genetic diversity		-0.037 (0.010) [p=0.000]		-0.040 (0.014) [p=0.004]	N/A
Number of domesticable animals		0.00093 (0.00025) [p=0.000]		0.0012 (0.00036) [p=0.001]	N/A
Neolithic transition timing (natural log)		-0.0071 (0.0020) [p=0.000]		-0.0065 (0.0027) [p=0.018]	N/A
Ancestry-adjusted years since agriculture (in thousands)		0.0014 (0.00051) [p=0.006]		0.0015 (0.00067) [p=0.025]	N/A

Table 2.4. Continued

	Dependent variable:				
	OLS (11)	**OLS (12)**	**SAR-OLS (13)**	**SAR-OLS (14)**	**SAR-FE (15)**
Population in 1000 (natural log)		0.0012 (0.00036) [p=0.001]		0.00095 (0.00051) [p=0.064]	N/A
Time fixed effects	Y	Y	N/A	N/A	Y
Missing natural capital dummy	Y	Y	Y	Y	Y
Spatial lag of the dependent variable			0.56 (0.22) [p=0.013]	-0.61 (0.31) [p=0.048]	0.61 (0.17) [p=0.000]
N	560	364	140	91	560
#-countries	140	91	140	91	140
(Pseudo) R^2	0.513	0.689	0.646	0.803	

Notes: The table reports a standard OLS log-linear model to test β-convergence in annual growth rates of per capita Inclusive Wealth, conditionally and unconditionally. Standard errors are in parentheses. P-values are in square brackets. The standard OLS models (11) and (12) cluster standard errors at the country level. The number of observations for the conditional β convergence estimations in models (12) and (14) is lower due to missing control variable data. The spatial autoregressive model (SAR) with OLS does not allow repeated unit observations. Therefore, it considers one period of twenty years instead of four periods of five years. This reduces the number of observations and omits the time-fixed effects. The SAR fixed effects (FE) model contains no (time-invariant) control variables due to collinearity with the country-fixed effects. The SAR models use an inverse distance spatial weight matrix. The results using a contingency spatial weight matrix are presented in Appendix 2F. Results including an interaction effect are presented in Appendix 2G. The sample comprises 140 countries without steady-state control variables and 91 countries with steady-state control variables.

2

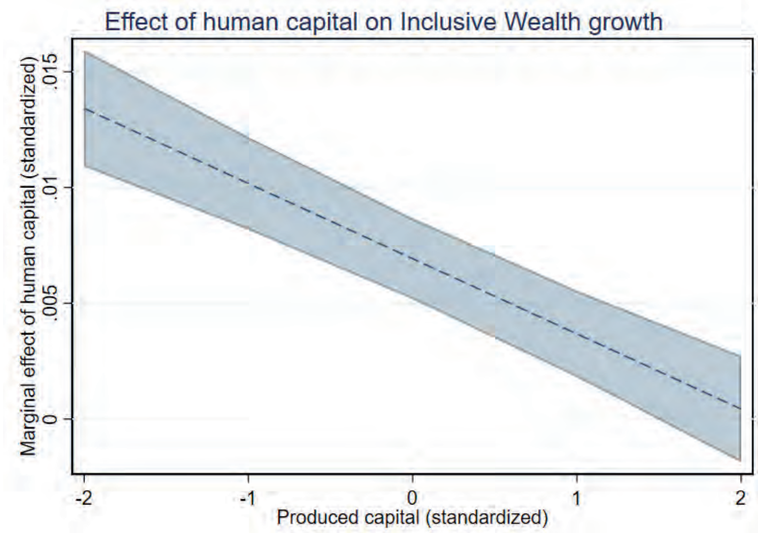
Table 2.4 presents the results of Inclusive Wealth's capital stocks as independent variables—human, produced, and natural capital. The analysis, therefore, attributes the source of unconditional wealth divergence and (supposed) conditional wealth convergence to specific capital stocks.[10] The main findings are that human capital has a positive coefficient, indicating a positive association between human capital and Inclusive Wealth growth. As levels of per capita Inclusive Wealth and human capital are highly correlated (0.89), ceteris paribus, developed countries accumulate wealth faster. The negative coefficient of natural capital indicates that natural resource abundance is associated with lower rates of Inclusive Wealth growth. Natural capital-abundant countries approximate the center of the cross-country wealth distribution (Figure 2.2), suggesting that poor and natural capital-dependent countries converge. Similarly, developed- and natural capital-dependent countries diverge.[11] Finally, the coefficient for produced capital is mostly statistically insignificant.

These findings indicate that the ratio of natural-to-human capital explains much of the cross-country variation in Inclusive Wealth growth. A country with as much human and natural capital balances the positive and negative effects on Inclusive Wealth growth. 45 out of 140 countries have more natural than human capital, implying that, all else equal, their wealth composition contributes to negative wealth growth. Furthermore, the model predicts that two identical countries with natural capital differentials will converge over time.

Additional analyses in Appendix 2G show that the statistically insignificant coefficient for produced capital hides heterogeneous effects. Figure 2.3 depicts these, showing how the effects of human and natural capital are moderated by produced capital. Alternatively, produced capital can be moderated by human or produced capital, as these correlates do not imply causation. The first panel illustrates how human capital's effect is positive but downward sloping for produced capital-abundant countries. This can also be interpreted as a downward sloping curve of produced capital, indicating diminishing marginal returns. Conversely, the second panel illustrates that produced capital increases the effect of natural capital on Inclusive Wealth growth. As such, resource-

10. The more robust BCFE models cannot exclude Inclusive Wealth as an independent variable. Adding the lagged capital stocks creates partial identification, leading to a multicollinearity problem.

11. The β-coefficients only present averages per capital stock and cannot decompose divergence or convergence by country type. Appendix 2H illustrates growth rate differentials by country types and Inclusive Wealth quartiles.



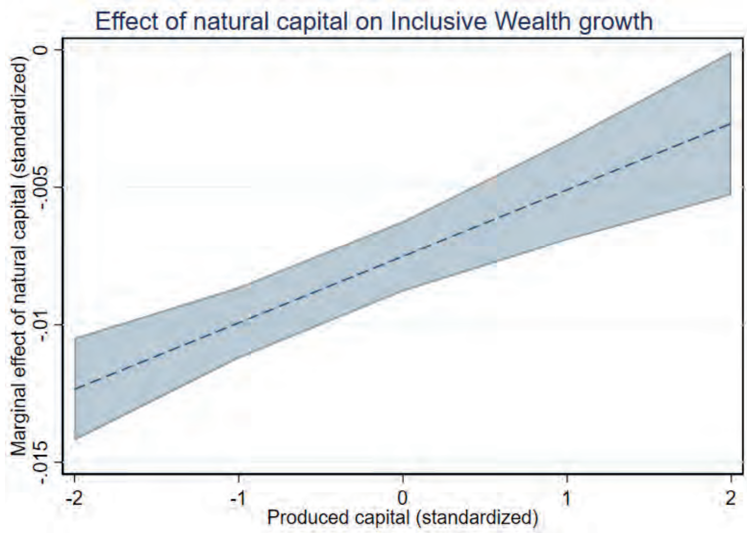


Figure 2.3.Interaction plots of conditional β-convergence analyses

Notes: The figure plots the interaction effects in the decomposed model of conditional wealth convergence (see Appendix 2G). The first panel illustrates the slope of human capital's effect on Inclusive Wealth growth moderated by produced capital (standardized). The second panel illustrates the slope of natural capital's effect on Inclusive Wealth growth moderated by the same values of standardized produced capital. The confidence intervals are at 95%

rich countries appear better able to achieve sustainable development when they have more produced capital, which could be an indication of a developed manufacturing industry. Chapter 4 finds additional evidence that natural capital is less unsustainable when domestic industries are larger.

I summarize the main findings as follows. Contrary to per capita GDP convergence, the analysis does not support β-convergence in per capita Inclusive Wealth. Instead, developed countries grow per capita wealth faster than poorer countries. I verify these findings using a range of non-parametric convergence techniques next.

2.5.2. Non-parametric techniques: σ-convergence and stochastic convergence

Table 2.5. σ-convergence of Inclusive Wealth between 1990 and 2010

	Dependent variable: $lnSD_t = \left[\left(\frac{1}{n}\right)\sum\left(lnY_{it} - \overline{lnY_t}\right)^2\right]^{0.5}$	
	Coefficient	**Implied speed of divergence**
Year	0.014 (0.002) [p=0.006]	0.0145
Constant	1.38 (0.007) [p=0.000]	
N	5	
#-countries	140	
R^2	0.9425	

Notes: The table indicates a simple regression where the statistical dispersion of natural log per capita Inclusive Wealth is regressed on time. Robust standard errors are in parentheses. P-values are in square brackets. The rate of divergence is calculated using .

Table 2.5 shows the estimates of σ-convergence of per capita Inclusive Wealth between 1990 and 2010. The positive coefficient indicates that the statistical dispersion of the natural log of per capita Inclusive Wealth increases during this period (i.e., σ-divergence). As the analyses do not account for steady state control variables, the results support unconditional divergence of Inclusive Wealth. The baseline analysis is not an artifact of taking growth rates as dependent variables. Level effects support divergence as well. However, σ-divergence seems to slow down at the end of the sample period. It will be interesting to monitor the evolution of σ-divergence in the future.

Regarding cross-country heterogeneity, there is σ-convergence among developed countries, suggesting that wealth gaps among the wealthiest diffuse very slowly. σ-divergence is increasing gaps among poor and natural resource-rich countries, suggesting that some countries accumulate Inclusive Wealth faster while others stay behind.

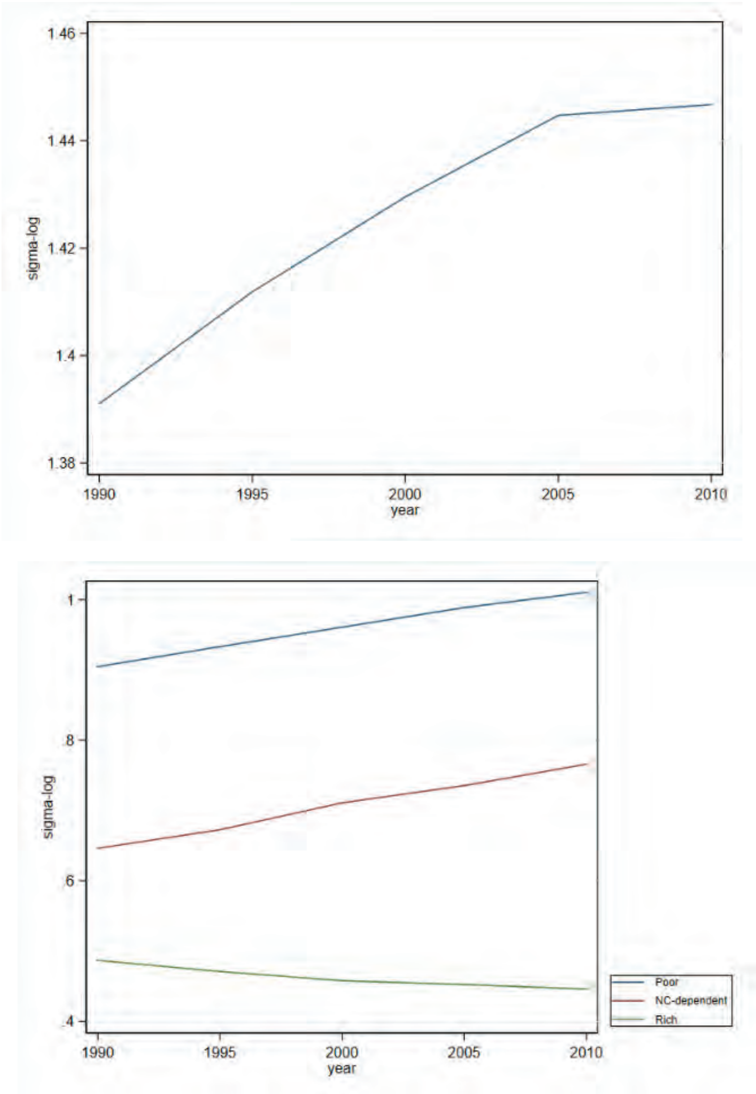


Figure 2.4. σ-divergence of Inclusive Wealth over time

Notes: Graphs indicate σ of per capita Inclusive Wealth (natural log) at five-year intervals. The second panel decomposes σ into three country types. See Appendix 2A for the categorization method.

Table 2.6. Stochastic convergence: Panel unit root tests between 1990-2010

Method	Natural log IW per capita			Natural log per capita GDP			
	Statistic ($\bar{t}$ or χ^2)	p-value	N (T)	Statistic ($\bar{t}$ or χ^2)	Lags (AIC)	p-value	N (T)
Im, Pesaran, and Shin	-1.669	>10%	140 (5)	-1.344	1.44	0.090	137 (21)
Im, Pesaran, and Shin (incl. trend)	-13.822	<1%	140 (5)	-4.676	2.12	0.000	137 (21)
MW Fisher	974	0.000	140 (5)	362	3	0.003	137 (21)
MW Fisher (incl. drift)	516	0.000	140 (5)	698	3	0.000	137 (21)
MW Fisher (incl. trend)	1582	0.000	140 (5)	441	3	0.000	137 (21)

Notes: The table reports the statistics for the IPS and Fisher methods of panel unit root tests for stochastic convergence. All tests include panel means. Lags are absent from Inclusive Wealth estimations due to an insufficient number of periods. Statistically significant outcomes indicate that at least some countries in the panel converge. The IPS cannot calculate p-values for Inclusive Wealth, which require a minimum T of 6 and 7 for without and with trends, respectively. However, critical values at 1%, 5%, and 10% are given. The Fisher model cannot be estimated with both a trend and drift due to insufficient degrees of freedom.

Table 2.6 shows the Fisher and IPS panel unit root test results for stochastic convergence. It reports the inverse χ^2 and statistics, respectively, and their accompanying p-values. The results reject the null hypothesis of no stochastic convergence, except for the IPS test that excludes a trend. In other words, the analysis demonstrates that at least one country in the panel converges stochastically.[12] The implication is that, for those countries, permanent or country-specific shocks affect long run relative Inclusive Wealth or GDP differentials only temporarily. However, the Fisher and IPS type tests neither inform us about the speed of convergence nor the share of countries that converge. Therefore, the results appear consistent with other techniques in the chapter that find convergence among groups of countries but not across the entire distribution.

Drawing on non-parametric analyses, I conclude that statistical dispersion across countries in terms of Inclusive Wealth is increasing (σ-divergence) while there are some convergence intra-distribution dynamics. The following section explores these further.

12. A caveat is that stochastic Inclusive Wealth convergence is estimated without lags. Ideally, the AIC or BIC criterion determines the number of augmented dickey-fuller lags to account for serial correlation and improve model fit. However, the lags are standard practice, but the short time horizon (T=5) prevents their use. Hence, the reliability of these tests is unclear.

2.5.3. Heterogeneity of Inclusive Wealth convergence

This section considers heterogeneity in convergence dynamics across the distribution. Table 2.7 presents the results of the Blinder-Oaxaca Decomposition analysis. The independent variable is operationalized as countries' change of position in the cross-country wealth distribution. Negative coefficients indicate a deterioration of per capita wealth relative to the global mean. Both analyses in the table compare two groups. The left column displays the comparison results between poor and natural capital-dependent countries, and the right column indicates results for rich and natural capital-dependent countries.

Table 2.7. The sources of divergence by country group: Blinder-Oaxaca decomposition

	Poor vs natural-capital dependent (16)	**Rich vs natural-capital dependent (17)**
Change in position in wealth distribution by Poor/Rich	0.0171 (0.00274) [p=0.000]	0.0228 (0.00229) [p=0.000]
Change in position in wealth distribution by Natural capital-dependent	-0.0365 (0.00433) [p=0.000]	-0.0365 (0.00433) [p=0.000]
Difference change in position	0.0536 (0.00512) [p=0.000]	0.0593 (0.00490) [p=0.000]
Explained by endowments	0.0393 (0.00597) [p=0.000]	0.0711 (0.0182) [p=0.000]
Unexplained by endowments	0.0143 (0.00521) [p=0.006]	-0.0118 (0.0187) [p=0.527]
Endowment factor breakdown		
Human capital	-0.00273 (0.00248) [p=0.271]	0.0188 (0.00988) [p=0.057]
Natural capital	0.0395 (0.00473) [p=0.000]	0.0255 (0.00470) [p=0.000]
Produced capital	-0.00306 (0.00170) [p=0.072]	0.0205 (0.00763) [p=0.007]
Control variables		
Control variables	Yes	Yes
N	252	172

Notes: Robust standard errors (in parentheses) clustered at the country level. P-values are in square brackets. The sample comprises 91 countries and 424 observations, constituting a unique country-year combination. Change in position in wealth distribution in the first two rows denotes the change in standardized log per capita Inclusive Wealth level.

The first column shows that poor countries outgrow natural capital-dependent countries. A representative poor country has improved its position in the distribution by 0.054 standard deviations between 1990 and 2010 relative to a representative natural capital-dependent country. Differences in explanatory variables account for most of the gap (0.039), which is fully explained by natural capital differences (0.040). Given that natural capital-dependent countries are generally wealthier (Figure 2.2), the analysis implies that poor and natural capital-dependent countries converge. More concretely, natural capital differentials drive cross-country wealth convergence in the lower segment of the wealth distribution, matching evidence of stochastic convergence. However, part of the performance gap (0.014) is unexplained by endowments. Factors beyond the pool of explanatory variables hamper natural capital-dependent countries or benefit poor countries.

The second column in Table 2.7 shows that rich countries outperform natural capital-dependent countries. A representative rich country has improved its position in the distribution by 0.059 standard deviations between 1990 and 2010 relative to a representative natural capital-dependent country. Interestingly, the gap explained by endowments (0.071) exceeds the observed gap. Differences in capital endowment contribute roughly equally to the explained component. The lower levels of natural capital and higher levels of human- and produced capital in rich countries confer an economic advantage relative to natural capital-dependent countries. Additionally, the unexplained component signals an unobserved advantage for natural capital-dependent countries (-0.012). If capital endowments and observed steady-state properties were identical between the two groups of countries, then natural capital-dependent economies would slowly catch up. Variables beyond the regular pool benefit natural capital-dependent relative to rich countries.

The takeaway message is that poor and rich countries outperform natural capital-dependent economies by the same margin. Ergo, poor and rich countries are neither converging nor diverging. However, there is convergence between the lower and the middle segment of the cross-country wealth distribution. Assuming the current trends persist, the normal distribution of cross-country per capita wealth gradually morphs into a bimodal distribution with a voluminous lower-wealth peak. An open question, however, is how some outliers with low human- and produced capital managed to outgrow their peers (e.g., China, Korea, Uruguay, Latvia).

Table 2.8 presents the quantile regression results following the best-fitting decomposed results from the decomposed Inclusive Wealth analysis with an interaction effect in Appendix 2G. The columns present coefficients from the worst-performing (Q10) to the best-performing (Q90) representative countries from left to right. The dependent variable is countries' change in per capita wealth relative to the global mean. Each coefficient indicates the effect of an explanatory variable on distributional change. Results confirm that wealth composition is the main factor reshaping cross-country wealth distribution. They are as follows.

1. Natural capital is associated with lower relative wealth growth regardless of the quantile; the effect is present even in top-performing countries.
2. The positive coefficient of the human capital shows that the larger the human capital stock, the better the country's performance relative to others. Human capital again emerges as a strong driver of convergence dynamics.
3. Produced capital's positive coefficient shows that the larger the produced capital stock, the higher the rate of wealth growth.

The findings underline that capital endowments explain the general trend of divergence well. However, the explanatory power of the model decreases for higher quantiles. Thus, capital endowments and steady state control variables are better able to explain general divergence than idiosyncratic catch-up experiences. I encourage further research on positive outliers.

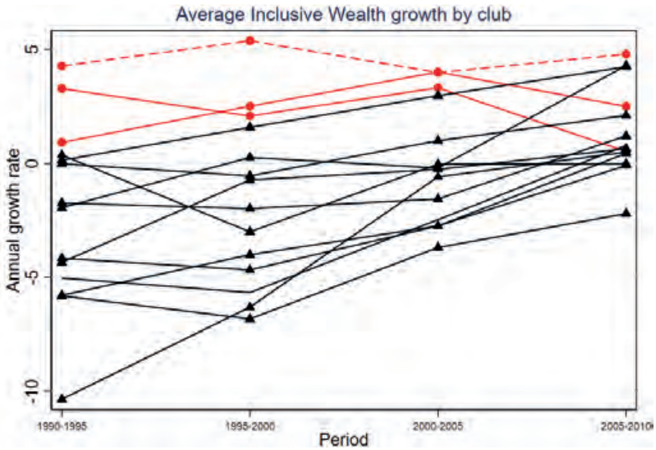


Figure 2.5. Inclusive wealth growth across convergence clubs

Notes: The graph indicates the average growth rate per convergence club established by the Phillips and Sul algorithm. Red lines (dots) indicate the four wealthy clubs. Black lines (triangles) indicate all other clubs. One line is dashed to separate its trajectory after 2000-2005 from the overlapping club.

Table 2.8. Heterogeneity in convergence analysis: Quantile regression of standardized Inclusive Wealth growth

	Dependent variable: Change in standardized per capita Inclusive Wealth				
	Q10	**Q25**	**Q50**	**Q75**	**Q90**
	(18)	**(19)**	**(20)**	**(21)**	**(22)**
Human capital (natural log)	0.043 (0.0058) [p=0.000]	0.052 (0.0092) [p=0.000]	0.045 (0.0063) [p=0.000]	0.042 (0.011) [p=0.000]	0.053 (0.011) [p=0.000]
Produced capital (natural log)	0.036 (0.0056) [p=0.000]	0.043 (0.0091) [p=0.000]	0.041 (0.0065) [p=0.000]	0.030 (0.013) [p=0.027]	0.032 (0.011) [p=0.005]
Natural capital (natural log)	-0.018 (0.0012) [p=0.000]	-0.019 (0.0015) [p=0.000]	-0.021 (0.0013) [p=0.000]	-0.020 (0.0018) [p=0.000]	-0.020 (0.0021) [p=0.000]
Interaction Variable					
Human capital × Produced capital	-0.0036 (0.0006) [p=0.000]	-0.0042 (0.00093) [p=0.000]	-0.0038 (0.00067) [p=0.000]	-0.0032 (0.0010) [p=0.002]	-0.0042 (0.0012) [p=0.000]
Control Variables					
Population density in 1500	-0.00016 (0.00023) [p=0.494]	-0.00023 (0.00027) [p=0.402]	-0.00059 (0.00023) [p=0.009]	-0.00047 (0.00015) [p=0.002]	-0.00047 (0.00029) [p=0.102]
Timing of the use of plough	-0.0057 (0.0076) [p=0.456]	-0.0079 (0.0078) [p=0.308]	-0.0091 (0.0057) [p=0.112]	-0.0049 (0.0080) [p=0.538]	0.019 (0.011) [p=0.083]
Distance from the technological frontier in 1500 (natural log)	0.00017 (0.00075) [p=0.821]	0.00039 (0.00065) [p=0.544]	0.0013 (0.0012) [p=0.291]	-0.0012 (0.0017) [p=0.504]	-0.0021 (0.0039) [p=0.594]
Predicted genetic diversity	-0.046 (0.026) [p=0.082]	-0.054 (0.038) [p=0.159]	-0.079 (0.031) [p=0.011]	-0.11 (0.045) [p=0.011]	-0.20 (0.049) [p=0.000]
Number of domesticable animals	0.0011 (0.00082) [p=0.175]	0.0029 (0.00097) [p=0.003]	0.0033 (0.00079) [p=0.000]	0.0038 (0.0012) [p=0.002]	0.0073 (0.0014) [p=0.000]
Neolithic transition timing (natural log)	-0.019 (0.0064) [p=0.004]	-0.035 (0.0081) [p=0.000]	-0.028 (0.0050) [p=0.000]	-0.018 (0.0082) [p=0.028]	-0.031 (0.013) [p=0.021]
Ancestry-adjusted years since agriculture (in thousands)	0.0045 (0.0014) [p=0.002]	0.0053 (0.0019) [p=0.007]	0.0059 (0.0016) [p=0.000]	0.0032 (0.0021) [p=0.132]	-0.0020 (0.0027) [p=0.457]
Population in 1000 (natural log)	0.0065 (0.0014) [p=0.000]	0.0063 (0.0015) [p=0.000]	0.0058 (0.0012) [p=0.000]	0.0047 (0.0012) [p=0.000]	0.0040 (0.0019) [p=0.031]

Table 2.8. Continued

	Dependent variable: Change in standardized per capita Inclusive Wealth				
	Q10	**Q25**	**Q50**	**Q75**	**Q90**
	(18)	**(19)**	**(20)**	**(21)**	**(22)**
Time fixed effects	Y	Y	Y	Y	Y
Missing natural capital dummy	Y	Y	Y	Y	Y
N	364	364	364	364	364
#-countries	91	91	91	91	91
Pseudo R^2	0.558	0.517	0.438	0.355	0.328

Notes: Robust standard errors (in parentheses) are clustered at the country level. P-values are in square brackets. The sample comprises 91 countries and 364 observations, constituting a unique country-year combination. Q10 denotes the 10-percent quantile or worst-performing representative countries, and Q90 represents the 90-percent quantile or best-performing countries.

Table 2.9. Club convergence of Inclusive Wealth

Club	# of countries	$\hat{\beta}$ (SE)	t ($\widehat{\beta}$)	μ Inclusive Wealth per capita (1990)
1	22	0.140 (0.088)	1.60	459117
2	12	0.101 (0.117)	0.861	210078
3	11	0.065 (0.086)	0.757	134934
4	20	-0.097 (0.110)	-0.879	77161
5	7	1.47 (0.262)	5.61	71898
6	4	0.512 (2.35)	0.218	52565
7	13	0.637 (0.082)	7.73	39429
8	7	0.458 (0.206)	2.22	30220
9	5	1.60 (0.280)	5.72	25883
10	15	-0.093 (0.103)	-0.902	15420
11	10	0.196 (0.173)	1.13	12371
12	7	0.034 (0.087)	0.390	6701
13	2	8.380 (2.25)	3.40	5644
14	3	0.352 (0.085)	4.12	4153

Notes: Applied truncation parameter: r=0.33; applied critical value c=0. The t-statistic at 5% significance level is -1.645; at 1% significance level is -2.326. The table does not include two non-converging countries (Iceland and Sierra Leone).

Table 2.9 presents the results of the club convergence analysis following Phillips and Sul's approach. First, I reject the null hypothesis of conditional convergence for the entire sample. Then, the algorithm finds 14 convergence clubs of countries after merging adjacent clubs.[13] Results are read as follows: the null hypothesis is club convergence. A positive coefficient between 0 and 2 indicates conditional convergence, and a negative coefficient indicates divergence. Findings are that only 7 of 14 clubs show a statistically insignificant coefficient. There is club convergence which neither contributes to a pattern of divergence nor conditional convergence. The remaining clubs show patterns of conditional convergence but not convergence in terms of levels.[14] Hence, there is heterogeneity in Inclusive Wealth growth over the sample period, implying various steady states. However, clubs 1 through 4, containing 63 of the wealthiest countries, illustrated in red in Figure 2.5, show little evidence of convergence. Their average growth rates continue to exceed nearly all other clubs. Thus, there is no overall convergence throughout the distribution.

13. The complete list of countries belonging to each club is found in Appendix 2I.
14. This is the case when , which is the case for club 13, containing only 2 countries.

Any observed convergence dynamics typically concern the Inclusive Wealth distribution's middle- and lower segments.

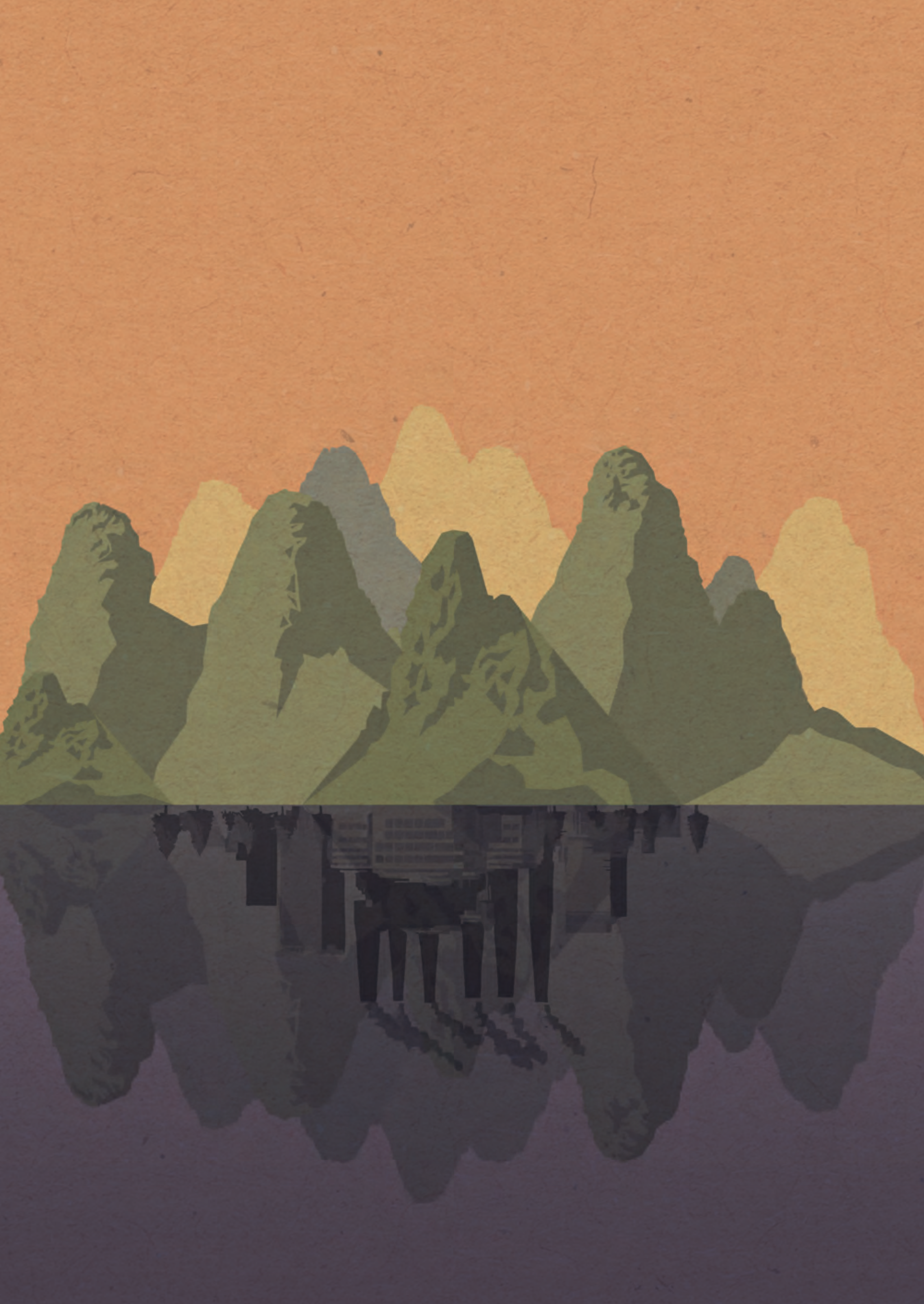
2.6. Conclusion

Although the recent studies on income convergence suggest that developing countries are catching up to the wealthy, this chapter portrays a grimmer outlook. The analyses validate the presence of unconditional cross-country convergence in national income. However, they also reveal concurrent divergence in Inclusive Wealth. This discrepancy cautions against optimism. Many countries are on an unsustainable path where they liquidate capital assets for income. They thus mortgage their future productive capacity and well-being for present-day consumption needs. The implication is that the increase in living standards implied by income convergence is untenable. Conversely, the evidence presented in this chapter suggests that global welfare inequalities are likely to increase rather than continue to decline.

The chapter identifies two main drivers of Inclusive Wealth divergence. First, human capital abundance fosters wealth growth, disproportionally benefiting developed countries. Second, natural capital abundance hampers wealth growth, increasing the gap between developed and natural capital-abundant economies. Natural capital's hampering effect may imply that the wealth gap between poor and natural capital-dependent countries is shrinking. However, the underlying mechanism is that the latter group of countries is regressing. Although this is technically a case of convergence, it is neither *catching up* nor in the spirit of the original convergence hypothesis.

This research indicates that a country's wealth composition predicts wealth growth more accurately than its Inclusive Wealth stock size. The higher the human-to-natural capital ratio, the better the performance. The culmination of forces means the cross-country distribution of per capita Inclusive Wealth gradually morphs into a bimodal one, with more countries in the low wealth peak. This general trend, however, does not guarantee a grim future for all developing economies. It also hides some countries' exemplary growth experiences during the sample period. Despite lacking human- and produced capital, they successfully defy the trend and move toward the club of wealthy economies. The convergence framework cannot explain these routes to success.

I encourage future researchers to study these positive outliers and replicate the study when the time horizon of Inclusive Wealth data expands. The short horizon, coupled with the inherent measurement error of the original data, has challenged addressing endogeneity. Once observations across time in the panel is sufficiently large, approaches such as system GMM become viable techniques for studying cross-country convergence. Given the variability of estimates, it is crucial to keep investing in better data.



Chapter 3.

Does natural capital depletion hamper sustainable development? Panel data evidence

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Abstract

This chapter addresses growing concerns that the global decline in natural capital hurts countries' well-being in the long run. I examine empirically how natural capital depletion affects sustainable development as measured by a positive change in the United Nation's Inclusive Wealth indicator. Drawing on panel data for 140 countries between 1990 and 2010, a within-country analysis reveals that natural capital depletion correlates positively with sustainable development. The rate of Inclusive Wealth growth increases as countries deplete more natural capital. However, some developed economies struggle to leverage their natural wealth for sustainable development. The policy implication is that there is no universally applicable recipe for the effective management of countries' natural resources. Countries that are poorly endowed with human- and produced capital, in particular, are in a window of opportunity in which natural capital depletion increases the rate of sustainable development.

3.1. Introduction

The worldwide depletion of natural capital helped trigger widespread concerns that societies do not manage their natural resources sustainably (Arrow et al. 2012). Sustainable development requires that natural resources be exploited without compromising the ability of future generations to satisfy their needs (Solow 1974). The loss in welfare from resource extraction can be mitigated by ensuring that natural resource revenues are reinvested sufficiently in other capital assets (Collier et al. 2010; Hamilton 1995; Hartwick 1977). Notably, converting depleted natural capital into forms of human- and produced capital can maintain intergenerational well-being, a critical part of a sustainable development agenda (Maler and Dasgupta 2000).

The debate on whether countries successfully convert natural capital sufficiently is far from settled. The limited empirical work finds that the shares of natural resource rents and exports as a percentage of GDP are negatively associated with inclusive wealth growth (Atkinson and Hamilton 2003; Boos and Holm-Müller 2013; Dietz et al. 2007; Forson et al. 2017; Hess 2010; Koirala and Pradhan 2020; Neumayer 2004). Hence, these studies suggest that undiversified economies not only experience lower income growth (Abdulahi et al. 2019; Pèrez and Claveria 2020; see Papyrakis 2017 for survey), [1] but also face a reduced capacity to develop sustainably. However, new evidence shows that natural resource exploitation may foster human- or produced capital accumulation (Lashitew and Werker 2020; Ouoba 2020; Sun et al. 2019; Zallé 2019), which suggests natural resource dependence need not be a curse for sustainable development. This calls for a comprehensive empirical analysis that evaluates if the global decline in natural capital has hindered or promoted sustainable development.

This chapter contributes to the literature by analyzing the net effect of natural capital depletion on sustainable development for a large panel of 140 countries from 1990 to 2010. Its empirical analysis employs Inclusive Wealth data (UNU-IHDP-UNEP 2015), which comprises human, produced,

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1. Among these studies, Dietz. et al. (2007) consider the moderating influence of institutions on wealth growth. Other work reports a similar moderating effect of institutions on development measured by GDP growth (Abdulahi et al. 2019; Boschini et al. 2007; Mehlum et al. 2006; Pérez and Claveria 2020), subjective well-being (Mignamissi and Kuete 2021), and Human Development Index (Daniele 2011). Institutional quality is also found to have a direct effect on sustainable development, independent from natural resource wealth (Aidt 2011; Forson et al. 2017; Sato et al. 2018; Venard 2013).

and natural capital. The time-series level-data on each stock allows me to study the biophysical decline of natural capital instead of relying on the imperfect and highly criticized proxies of resource usage (Brunnschweiler and Bulte 2008; James 2005; Stijns 2005). Moreover, Inclusive Wealth accounting is considered by many to be a state-of-the-art measure of sustainable development (Clark and Harley 2020; Dasgupta 2014; Engelbrecht 2016; Polasky et al. 2015). It indicates a country's overall economic prosperity and ability to meet Sustainable Development Goals, rendering it particularly useful to derive policy prescriptions (Dasgupta 2014).

The study employs fixed effects regressions that examine how within-country changes in natural, produced, and human capital affect per capita Inclusive Wealth growth rates. I focus, in particular, on cross-country differences by evaluating if economies that depend heavily on natural capital (i.e., natural resource-dependence) achieve lower rates of Inclusive Wealth growth when depleting natural capital. To this end, I introduce a new empirical measure of resource dependence and perform various sensitivity analyses with traditional but less suitable measures of resource dependence. Results indicate that natural capital depletion is associated positively with per capita Inclusive Wealth growth, but not for all countries. Although natural capital depletion increases the rate of sustainable development in developing and resource-dependent economies, it may have no or even a negative effect in several developed countries.

The rest of this chapter is organized as follows. Section 3.2 briefly discusses the conceptual links among economic performance, inclusive wealth, and sustainability before formulating hypotheses. Section 3.3 details the data and empirical approach. Section 3.4 presents the results and various sensitivity analyses. Section 3.5 summarizes the main findings and provides some concluding remarks.

3.2. Background and hypotheses

There has been a growing academic interest in the sustainable exploitation of natural resources (e.g., Blanco and Grier 2012; Mardones 2019; Ouoba 2020; Qureshi et al. 2019). The attention is fueled, in part, by resource-rich economies' persistent struggle to develop sustainably. Although many resource-rich economies (e.g., Liberia, Qatar, United Arab Emirates) are often able to achieve impressive rates of per capita GDP growth (World Bank Group 2019), they also face a shrinking capital stock and corresponding deterioration of their future productive capacity (UNU-IHDP-UNEP, 2015). The sustainable extraction of natural resources requires that depleted natural capital be compensated by an accumulation of produced- and human capital assets that make an equal or greater contribution to welfare (Hartwick 1977).

In this light, the Inclusive Wealth approach measures the productive capacity of an economy by estimating its productive base, comprising all capital assets:[2] (i) human, (ii) produced, and (iii) natural. If the productive base grows, future generations will have more resources and, therefore, an improved ability to support and raise their standard of living. Resonating with weak sustainability (Arrow et al. 2012; Pearce et al. 1996), sustainable development entails non-declining per capita Inclusive Wealth stocks.

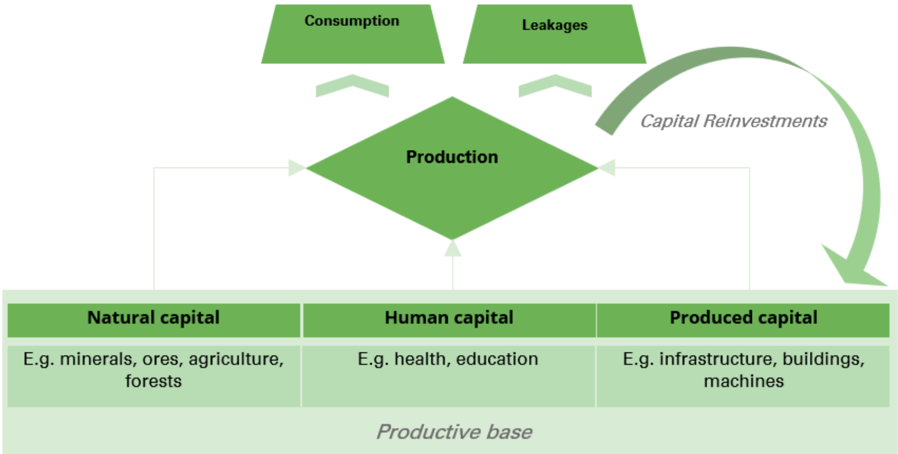

Figure 3.1. Model of capital conversion and sustainable development

Notes: The graph illustrates how the productive base comprising natural, produced, and human capital assets drives sustainable development. Capital stocks supply resource flows to the production of goods and services, which can be reinvested in as new capital to develop sustainably or used for present-day needs such as consumption and other forms of leakages.

2. Some studies explicate social or intangible capital as a form of capital, which is an intangible source of productive capacity embedded in societal institutions. This study and others like it account for social capital implicitly via shadow prices. Calculations of social capital do not yet meet the standards for empirical analysis to warrant a separate stock value (Engelbrecht, 2016).

Figure 3.1 illustrates how economies can grow inclusive wealth. Each capital stock (i.e., human, produced, and natural) supplies a flow of resources to production. The resulting output, in turn, is either reinvested to form new capital or used to satisfy present-day needs. However, natural capital exploitation comes at a cost, as natural resources depreciate in production (Daly 2020).[3] Hence, enough output must be reinvested to compensate for the loss of natural capital and prevent a decline in inclusive wealth. Countries that rely heavily on natural resources in production must be particularly cautious and safeguard a high rate of capital reinvestment to prevent overconsumption in the short run. Nevertheless, even the most vulnerable countries can extract natural resources sustainably as long as these are sufficiently transformed into produced- and human capital (Hartwick 1976).

Theoretically, countries' ability to convert natural capital into other forms of wealth differs due to diminishing returns to capital accumulation (Johnson and Papageorgiou 2020; Krugman 1994). All else constant, developing economies possess fewer produced capital assets and are sparse in human capital, as underscored by lower longevity and educational outcomes. As a result, these economies accumulate produced- and human capital more easily. For instance, the investment necessary to achieve higher educational attainment is modest when a population is undereducated. Similarly, when natural resources are exploited, the share of resource revenues required to be reinvested in produced- and human capital to compensate for the loss of natural wealth is much lower in developed economies.

Conversely, diminishing returns to human- and produced capital accumulation become a more significant barrier as economies develop, increasing the required reinvestment of natural resource revenues to develop sustainably. Although it may appear disadvantageous for developed economies, evidence suggests that developed economies better utilize their natural capital (Kurniawan and Managi 2018). I therefore propose the following general hypothesis (H1):

Hypothesis 1 Natural capital depletion increases a country’s rate of Inclusive Wealth growth.

3. Natural resources become physically embodied in the product, whereas labor and produced capital inputs do not.

In contrast to the main hypothesis, most empirical studies find a negative association between some operationalization of natural capital and inclusive wealth growth (Atkinson and Hamilton 2003; Boos and Holm-Müller 2012, 2013; Dietz et al. 2007; Kurniawan and Managi 2019). These studies propose that resource-dependent economies fail to reap the theoretical gains and instead squander natural resource revenues. Boos and Holm-Müller's (2013) theoretical overview of the literature offers the following explanation.[4]

Resource dependence often accompanies or may even cause political systems inconducive to wealth growth. Governments in natural resource-dependent countries may become rentier states (Turan and Yanıkkaya 2020). Resource rents provide a vast share of government revenues in these countries, exemplified by Nigeria where 95% of government revenues stem from the resource sector (Gupta and Chu 2018). More importantly, these rents are used mainly for government consumption, corruption, and other forms of short-term wastage instead of productive investments (Barbier 2010; Lange and Wright 2004; Papyrakis and Gerlagh 2004). Hence, the lack of proper institutions discourages investment in human capital while encouraging natural capital depletion. The perverse incentives that hamper sustainability resulting from resource dependence may even extend beyond the natural capital sector. I therefore formulate the following hypothesis (H2):[5]

Hypothesis 2 Natural capital depletion decreases a country's rate of Inclusive Wealth growth in natural resource-dependent countries.

I test the hypotheses using panel data for up to 140 countries. The following section details these data and the empirical approach to testing these hypotheses.

4. Section 4.2.2 offers a more comprehensive overview of potential channels underlying the negative association between resource-dependence and inclusive wealth growth.

5. In addition to Hypothesis 2, a leakage beyond the resource sector is the crowding-out of human capital accumulation by resource dependence (Cockx & Francken 2016). To be complete, the empirical strategy also considers this potential transmission channel of resource dependence-induced wastage.

3.3. Data and method

3.3.1. Data

3.3.1.1. Data source and sample

The main data source for this chapter is the Inclusive Wealth Report developed by the United Nations Environment Programme and the United Nations University - International Human Dimensions Program (UNU-IHDP-UNEP 2015). The Inclusive Wealth indicator measures countries' total wealth by aggregating the natural, produced, and human capital stocks. The data provides real dollar values of each capital stock for 140 countries at five moments (1990, 1995, 2000, 2005, and 2010). Together, these countries cover 95% of the world's population. Table 3.1 provides key summary statistics for the variables discussed below.

3.3.1.2. Dependent variable

Sustainable development, the dependent variable, is measured as the percentage change in per capita Inclusive Wealth over 5-year intervals. Inclusive Wealth growth rates are slightly positive on average (Table 3.1; see also Table A1 in Appendix 2A) and distributed normally across countries. The best-performing countries have an average growth rate of some 10%, whereas poorly performing countries have a growth rate of around -10%. Several countries experience large, idiosyncratic drops in Inclusive Wealth, frequently due to events like wars or conflicts, primarily via sharp declines in produced capital. A sensitivity analysis controls for these (Appendix 3A).

3.3.1.3. Main independent variables

The main independent variables are countries' per capita human, produced, and natural capital stocks.[6] Data on each stock comes from the Inclusive Wealth report's data appendix. I calculate the natural logarithms of each stock, as is common in growth accounting (Mankiw et al. 1992). Per capita human capital is the largest capital stock, whereas natural capital exhibits the most cross-country variation. Mostly oil states have vast natural capital wealth (e.g., Qatar, Kuwait, United Arab Emirates); others are natural resource-scarce (e.g., Singapore, Maldives, Haiti, Lesotho). More importantly, I identify several countries that have experienced significant drops in human capital (i.e., Moldova), produced capital (e.g., Afghanistan, Liberia, United Arab

6. I use a fixed-effects regression analysis and thus effectively study the changes in these stocks.

Table 3.1. Descriptive statistics for selected variables

	Complete sample [N = 140]	**Developing countries [N = 57]**	**Resource-dependent countries [N = 31]**	**Developed countries [N = 30]**	**Uncategorized countries [N = 22]**
Inclusive Wealth growth (%)	0.417 (0.071)	1.420 (5.644)	-5.027 (6.252)	5.031 (3.203)	-0.805 (0.960)
Human capital (natural log)	10.130 (1.614)	9.317 (1.058)	9.284 (1.180)	12.265 (0.445)	10.513 (1.543)
Produced capital (natural log)	9.034 (1.753)	8.036 (1.283)	8.376 (1.189)	11.290 (0.506)	9.468 (1.633)
Natural capital (natural log)	8.805 (1.855)	7.855 (1.218)	10.313 (0.795)	8.648 (1.92)	9.355 (2.520)
Natural capital share (standardized)	-.000 (1.000)	-0.273 (0.391)	1.200 (0.894)	-0.817 (0.286)	0.129 (0.988)
Mineral exports as % of GDP	4.911 (10.050) (550 observations)	4.817 (10.040) (215 observations)	9.187 (13.376) (109 observations)	2.228 (1.797) (138 observations)	4.048 (11.275) (88 observations)

Notes: The table reports sample means and standard deviations (in parentheses). The number of countries per group in square brackets. Each country has five observations between 1990 and 2010 (5-year intervals) for each variable. The number of observations varies for mineral exports as % of GDP due to missing data in the original source (World Bank Group 2019).

3

Emirates), or natural capital (e.g., Bahrein, Qatar, United Kingdom, Greece) in at least one period. Sensitivity analyses confirm that these potential outliers do not bias the results.

3.3.1.4. Moderating variable: natural resource-dependence

I include an interaction variable for natural resource-dependence, which moderates the effect of natural capital accumulation on per capita Inclusive Wealth growth. I introduce a new indicator for natural resource dependence to address some of the many issues troubling conventional indicators (Brunnschweiler and Bulte 2008; Bulte et al. 2005; Dietz et al. 2007; Stijns 2005; Van der Ploeg 2011).[7] I consider countries to be natural resource-dependent when natural capital is overrepresented in the total wealth stock. Hence, I label countries as such when (1) human- and produced capital are scarce, and (2) natural capital is more abundant relative to countries with comparable human and produced capital scarcity. The second criterion distinguishes developing economies from resource-dependent ones. The indicator is robust to short-term fluctuations in economic activity because it is based on (the composition of) wealth, which changes gradually over time.

I operationalize this indicator following Ahmad et al.'s (2018) network-based frequency analysis that groups countries based on the relative abundance of types of capital. Briefly put, the method compares every country with every other and links them when values are close. The country with the most links becomes the trend, and the country-distance from this trend (orbital distance) determines relative abundance. Based on this analysis, countries have high- or low values of each type of capital, corresponding to a relative abundance or scarcity. For this chapter, I identify three groups of countries based on the orbital distance at the beginning of the sample period (1990).

The first group, comprising 57 developing countries, scores low on all capital types. The natural resource-dependent group contains 30 countries that

7. The conventional indicator of natural resource dependence is the share of the sum of raw material exports in GDP (Sachs & Warner, 1995; Atkinson & Hamilton, 2003; Dietz et al., 2007; Brunnschweiler & Bulte, 2008; Boos & Holm-Müller, 2013; Lashitew & Werker, 2020). This indicator is less suitable because it varies with (whimsical) short-term fluctuations in countries' market activity, international trade, and demand for raw materials. Therefore, it can contain systematic measurement errors (steepening slope bias). When world prices increase significantly, the measure gives a false positive indication of resource dependence. Vice versa, a drop in world prices underestimates resource dependence.

score low on produced- and human capital but high on natural capital. The 31 countries that score high on produced- and human capital are developed economies independent of natural capital abundance. Although I include the group of developed economies in the main analysis, I do not evaluate any hypotheses by doing so. The 22 remaining uncategorized countries are diverse and omitted from the main analysis. A time-invariant categorical variable indicates group membership, which takes a value of 1 for the developing countries (reference category), 2 for resource-dependent, and 3 for the developed countries. The time-invariant dummy is omitted from the analysis due to collinearity with the country-fixed effects, but the moderating effect is retained.

To be sure, for the reasons highlighted above, I prefer this indicator over common indicators of natural resource dependence. However, to be complete, I also repeat the main analysis using the following less suitable indicators as a sensitivity analysis. The first one measures natural resource dependence as the share of natural in total wealth (e.g., Gylfason 2001; Hodler 2006). The share of natural capital of total capital takes a value between 0 and 1, where 1 indicates the absence of produced- and human capital. The (standardized) variable interacts with each type of capital. The second one follows seminal papers (e.g., Atkinson and Hamilton 2003; Dietz et al. 2007; Sachs and Warner 1995) in which natural resource dependence is measured as the sum of raw mineral and ore exports as a percentage of GDP. The World Development Indicators database provides the data (World Bank Group 2019). Some data are missing, reducing the sample to 133 countries and 501 observations.

3.3.2. Empirical model

I use panel data to estimate the effect of natural, produced, and human capital changes on per capita Inclusive Wealth growth. All regressions use country-fixed effects models.[8] This approach evaluates the hypotheses by observing the within-country changes of each capital stock. The country-fixed effects capture all time-invariant heterogeneity among countries, including mean values of each capital stock and group membership. Additionally, fixed effects absorb time-invariant country-specific properties that influence economic performance, such as cultural heritage and geography (Temple 1999). Hence, the empirical model isolates the effect of changes to each capital stock (i.e.,

8. $\chi^2 = 41.84$ in the Hausman test for the baseline model, rejecting the null hypothesis and favoring the fixed-effects model over the random-effects model.

capital accumulation or depreciation) on the rate of Inclusive Wealth growth over time within economies. The empirical model that I estimate is as follows:

$$G_{it} = \beta_0 + \beta_1 N_{it} + \beta_2 H_{it} + \beta_3 P_{it} + R_i \times \begin{matrix} \beta_4 H_{it} \\ \beta_5 P_{it} \\ \beta_6 N_{it} \end{matrix} + T_t + \delta_i + \varepsilon_{it} \qquad \text{(Eq. 3.1)}$$

where G_{it} is the rate of per capita Inclusive Wealth growth for country *i* at time *t*, N_{it} is the natural log of natural capital per capita, H_{it} is the natural log of human capital per capita, and P_{it} is the natural log of produced capital per capita. R_i captures the moderating effect of natural resource dependence, which interacts with each main explanatory variable. I estimate this model for country *i* at time *t*, where δ_i is the country-fixed effect and ε_{it} the error term. I add time dummies T_t for each period to control for global periodic fluctuations in per capita Inclusive Wealth growth that are unaccounted for by the explanatory variables.

I expect the coefficient of *N* to be negative, thus supporting Hypothesis 1, which would indicate that natural resource depletion positively affects rates of Inclusive Wealth growth. I expect a positive coefficient for the interaction term *N*R*, supporting Hypothesis 2.[9] This would indicate that natural capital depletion has a less positive effect on the rate of Inclusive Wealth growth in resource-dependent countries relative to the reference category (developing economies). If the coefficient for N*R exceeds $|\beta_1|$ then the net effect of resource depletion in resource-dependent countries is negative, demonstrating the resource curse. Further, I expect negative coefficients for *H* and *P*, indicating diminishing returns to human- and produced capital accumulation, respectively.

3.4. Empirical results

3.4.1. Baseline results

Table 3.2 presents the results for different specifications of the model described by Equation 3.1. Akin to a standard neoclassical production function, Model 1 considers only human- and produced capital as sources of

9. Moderating variable R_i assesses the overall wastage induced by resource dependence. It could therefore also moderate any of the other independent variables negatively. The regression models consider all possible configurations.

Inclusive Wealth growth. Model 2 considers the effect of all three types of capital accumulation while not yet accounting for cross-country differences. The results show that natural capital depletion increases the rate of Inclusive Wealth growth, supporting Hypothesis 1. A one percent decrease in per capita natural capital increases the per capita Inclusive Wealth growth rate by approximately 0.06 percentage points. These findings are consistent with, but not sufficient evidence, for the idea that countries sufficiently convert natural resources. The results are interpretable in two ways. First, assuming countries convert natural resources sufficiently, the more they deplete, the higher the growth rate of Inclusive Wealth. Second, assuming countries do not convert natural resources sufficiently, Inclusive Wealth growth becomes less negative as they deplete natural resources. The second scenario could be when, for instance, less natural capital prompts countries to switch to using human- and produced capital more, assuming these are more productive capital stocks. Both scenarios outline an improving sustainable development path but assume different starting points. Hence, the results provide no conclusive answer to whether countries convert natural resources sufficiently.[10]

Human capital accumulation lowers the rate of Inclusive Wealth growth. A one percent increase in human capital per capita decreases a country's per capita Inclusive Wealth growth by approximately 0.26 percent, conditional on the model specification. This does not mean that human capital hampers sustainable development but that each subsequent increase in human capital results in a decreasing Inclusive Wealth gain. Produced capital's effect is not statistically significant. The lack of statistical significance persists throughout the main and sensitivity analyses. Chapter 2 shows that produced capital's interaction with human- and natural capital results in heterogeneous effect around zero.

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10. In the sample, only 10 out of 118 countries experienced an increase rather than a decrease in their per capita natural capital stock. These countries include Latvia, Belgium, Estonia, Cuba, and some Eastern European economies. The coefficient represents an average effect over the sample, meaning that it is possible these countries have lower rates of Inclusive Wealth growth due to natural capital accumulation.

Table 3.2. The effect of capital accumulation on sustainable development: moderation by country-type

	Dependent variable: per capita Inclusive Wealth growth (%)					
			Moderating effect: Country-type			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Human capital	-0.264 (0.063) [p=0.000]	-0.259 (0.061) [p=0.000]	-0.234 (0.064) [p=0.000]	-0.277 (0.057) [p=0.000]	-0.277 (0.058) [p=0.000]	-0.262 (0.089) [p=0.004]
Produced capital	0.008 (0.008) [p=0.665]	0.015 (0.017) [p=0.387]	0.021 (0.017) [p=0.210]	0.012 (0.023) [p=0.607]	0.022 (0.017) [p=0.198]	0.012 (0.025) [p=0.631]
Natural capital		-0.056 (0.019) [p=0.005]	-0.048 (0.018) [p=0.009]	-0.048 (0.017) [p=0.005]	-0.069 (0.022) [p=0.002]	-0.049 (0.025) [p=0.051]
Interaction terms						
Human capital × Resource-dependent (0/1)			0.052 (0.072) [p=0.469]			0.038 (0.120) [p=0.751]
Human capital × Developed (0/1)			-0.243 (0.062) [p=0.000]			-0.129 (0.094) [p=0.171]
Produced capital × Resource-dependent				0.036 (0.028) [p=0.199]		0.033 (0.032) [p=0.306]
Produced capital × Developed				-0.084(0.026) [p=0.002]		-0.043 (0.043) [p=0.323]
Natural capital × Resource-dependent					-0.0197 (0.025) [p=0.426]	0.006 (0.036) [p=0.874]
Natural capital × Developed					0.060 (0.021) [p=0.004]	0.005 (0.031) [p=0.859]
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2 within	0.248	0.285	0.330	0.336	0.308	0.342

Notes: The table reports results for the fixed effects model. Standard errors (in parentheses) are robust standard errors clustered at the country level. P-values are reported in square brackets. The sample comprises 118 countries and 472 observations. The moderating effect is a time-invariant categorical variable capturing country type (developing, resource-dependent, or developed), showing how capital accumulation/depletion affects sustainable development differently for each type (reference category: developing). The categorical variable (direct effect) is omitted due to collinearity with country-fixed effects.

Models 3 to 6 in Table 3.2 include a moderating effect indicating country type (developed, developing, or natural resource-dependent). The interaction effects mean that I evaluate whether each capital stock's accumulation affects Inclusive Wealth growth differently among country types. The results indicate no differences between developing countries (the reference category) and natural resource-dependent countries. In particular, the coefficient of natural capital for resource-dependent countries is insignificant in Model 5 and Model 6. Accordingly, natural capital does not have a statistically distinguishable relation to Inclusive Wealth between developing- and natural resource-dependent economies. Hence, I fail to find support for Hypothesis 2. Conversely, the analysis suggests that natural capital depletion has a positive association with the rate of Inclusive Wealth growth in natural resource-dependent countries. Similarly, no statistically significant difference exists in how produced- or human capital accumulation affects rates of sustainable development in resource-dependent economies.

Thus, the analysis yields no evidence against the idea that resource dependence hampers Inclusive Wealth growth via natural capital conversion. Conversely, natural capital depletion increases the rate of Inclusive Wealth growth in most economies. Interestingly, developed ones are the exception. I cannot confirm that natural capital depletion affects rates of Inclusive Wealth growth in these economies with statistical confidence. The inconclusive outcome underlines a need to look into the natural capital conversion process for mechanisms that explain the cross-country heterogeneity. Chapter 4 of this dissertation does so. I dedicate the remainder of this chapter to the robustness of the findings.

3.4.2. Sensitivity analyses

3.4.2.1. Alternative indicators of natural resource dependence: natural capital share

The first sensitivity analysis considers a different measurement of moderating variable, natural resource dependence: the share of natural capital in total wealth. Table 3.3 presents the results.

The main analysis' conclusion proves robust to this operationalization of resource dependence. Natural capital has a negative coefficient in Model 8, meaning that resource depletion increases Inclusive Wealth growth, supporting Hypothesis 1. However, the effect size has changed slightly relative to the baseline analysis (Table 3.2; Model 2). The difference comes from the

Table 3.3. Sensitivity analysis: The effect of capital accumulation on sustainable development: moderation by natural capital's share of wealth

	Dependent variable: per capita Inclusive Wealth growth (%)					
			Moderating effect: share of natural capital in total wealth			
	(7)	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
Human capital	-0.285 (0.062) [p=0.000]	-0.292 (0.062) [p=0.000]	-0.266 (0.068) [p=0.000]	-0.279 (0.073) [p=0.000]	-0.310 (0.063) [p=0.000]	-0.273 (0.073) [p=0.000]
Produced capital	-0.002 (0.018) [p=0.899]	0.004 (0.017) [p=0.836]	-0.000 (0.016) [p=0.982]	-0.008 (0.017) [p=0.639]	-0.008 (0.018) [p=0.640]	-0.005 (0.018) [p=0.791]
Natural capital		-0.043 (0.021) [p=0.044]	-0.017 (0.022) [p=0.445]	-0.017 (0.022) [p=0.430]	0.014 (0.026) [p=0.588]	0.006 (0.024) [p=0.798]
Resource-dependence			-0.369 (0.121) [p=0.003]	-0.173 (0.070) [p=0.015]	-0.327 (0.12) [p=0.009]	-0.511 (0.176) [p=0.004]
Interaction terms						
Human capital × Resource-dependence			0.033 (0.014) [p=0.022]			0.030 (0.021) [p=0.150]
Produced capital × Resource-dependence				0.015 (0.010) [p=0.124]		-0.004 (0.017) [p=0.798]
Natural capital × Resource-dependence					0.023 (0.012) [p=0.053]	0.018 (0.011) [p=0.105]
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2 within	0.155	0.174	0.219	0.205	0.220	0.236

Notes: The table reports results for the fixed effects model. Standard errors (in parentheses) are robust standard errors clustered at the country level. P-values are reported in square brackets. The sample comprises 140 countries and 560 observations. The moderating effect is the (standardized) share of natural capital in total wealth, showing how capital accumulation/depletion affects sustainable development differently for ratios of resource dependence. This analysis includes the direct effect of natural resource dependence and its interaction effects.

uncategorized 22 countries included in this sensitivity analysis but omitted in the main analysis. Human capital accumulation lowers the rate of per capita Inclusive Wealth growth, and produced capital accumulation again has no statistically significant effect.

Models 9 to 12 in Table 3.3 introduce the moderating effects of natural resource dependence. These models include a direct- and indirect (moderating) effect because the share of natural capital varies over time. The direct effect shows that a decreasing share of natural capital increases the rate of Inclusive Wealth growth. I do not find a statistically significant moderating effect of resource dependence on natural capital depletion, meaning I find no support for Hypothesis 2. However, I find a positive indirect effect via human capital accumulation. It suggests that human capital accumulation fosters Inclusive Wealth growth more in resource-dependent countries. This makes sense intuitively, as the marginal benefits of human capital accumulation are higher in countries where it is scarce.

3.4.2.2. Alternative indicators of natural resource dependence: resource exports and rents

The second sensitivity analysis operationalizes natural resource dependence as the sum of raw mineral and ore exports over GDP. This indicator of natural resource dependence is not expected to affect rates of Inclusive Wealth growth.[11] Nevertheless, the goal is to rule out biases due to the novel operationalization of resource dependence in the main analysis.

Table 3.4 presents the results. In contrast to extant studies using this metric (e.g., Boos and Holm-Müller 2012; Dietz et al. 2007), I find no evidence that higher resource exports hamper sustainable development. The coefficient for natural resource dependence is not statistically significant, neither as an explanatory variable nor as a moderator. I cannot claim that when countries increase resource exports, their wealth growth decreases. Mineral and ore exports as a percentage of GDP yields no other meaningful results as a moderating variable.

11. Flows of mineral exports as a percentage of GDP is an indicator of trade intensity by the natural resource sector but not an indicator of the structural importance of natural capital for long run development. A weak correlation between resource exports and other metrics of resource dependence underlines this.

I consider the possibility that the lack of meaningful results follows from the specific operationalization of resource trade intensity. Therefore, I add agricultural exports to mineral exports as a percentage of GDP, a common variation of this measure (Mehlum et al. 2006; Sachs and Warner 1995). Nevertheless, all coefficients for natural resource dependence remain statistically insignificant.[12] All findings are robust to restricting the sample to only countries with 3% or more resource exports as a share of GDP. I conclude that the main analysis' findings are robust to alternative ways to measure natural resource dependence.[13]

Finally, I repeat the exercise using natural resource rents as a percentage of GDP as the moderating variable for natural resource dependence. The results show that natural capital depletion increases per capita Inclusive Wealth growth rates. I do not find a negative relationship between natural resource rents and sustainable development. This is potentially explained by the high correlation between depleted natural capital and resource rents.

12. Not reported in Table 3.4.
13. Appendix 3A presents sensitivity analyses with additional moderators.

Table 3.4. Sensitivity analysis: The effect of capital accumulation on sustainable development: moderation by export resource intensity

	Dependent variable: per capita Inclusive Wealth growth (%)					
	Moderating effect: mineral exports as % of GDP					
	(13)	**(14)**	**(15)**	**(16)**	**(17)**	**(18)**
Human capital	-0.392 (0.067) [p=0.000]	-0.393 (0.068) [p=0.000]	-0.374 (0.068) [p=0.000]	-0.373 (0.068) [p=0.000]	-0.378 (0.067) [p=0.000]	-0.373 (0.068) [p=0.000]
Produced capital	-0.031 (0.031) [p=0.309]	-0.024 (0.030) [p=0.423]	-0.025 (0.031) [p=0.414]	-0.025 (0.030) [p=0.418]	-0.027 (0.030) [p=0.379]	-0.025 (0.030) [p=0.420]
Natural capital		-0.041 (0.029) [p=0.152]	-0.050 (0.030) [p=0.097]	-0.051 (0.031) [p=0.096]	-0.048 (0.029) [p=0.104]	-0.052 (0.031) [p=0.099]
Resource-dependence			-0.020 (0.019) [p=0.312]	-0.016 (0.015) [p=0.291]	-0.006 (0.015) [p=0.683]	-0.002 (0.049) [p=0.970]
Interaction terms						
Human capital × Resource-dependence			0.003 (0.002) [p=0.189]			-0.004 (0.011) [p=0.728]
Produced capital × Resource-dependence				0.003 (0.002) [p=0.170]		0.006 (0.010) [p=0.575]
Natural capital × Resource-dependence					0.001 (0.001) [p=0.381]	-0.000 (0.003) [p=0.879]
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2 within	0.177	0.193	0.202	0.203	0.201	0.203

Notes: The table reports results for the fixed effects model. Standard errors (in parentheses) are robust standard errors clustered at the country level. P-values are reported in square brackets. The sample comprises 133 countries and 427 observations. The moderating effect is the flow of mineral and ore exports as a percentage of GDP, showing how resource trade intensity affects sustainable development directly and indirectly by moderating capital accumulation/depletion. Alternative operationalizations used but not reported are the flow of natural resource exports as a percentage of GDP, natural resource rents as a percentage of GDP, and oil rents as a percentage of GDP.

3

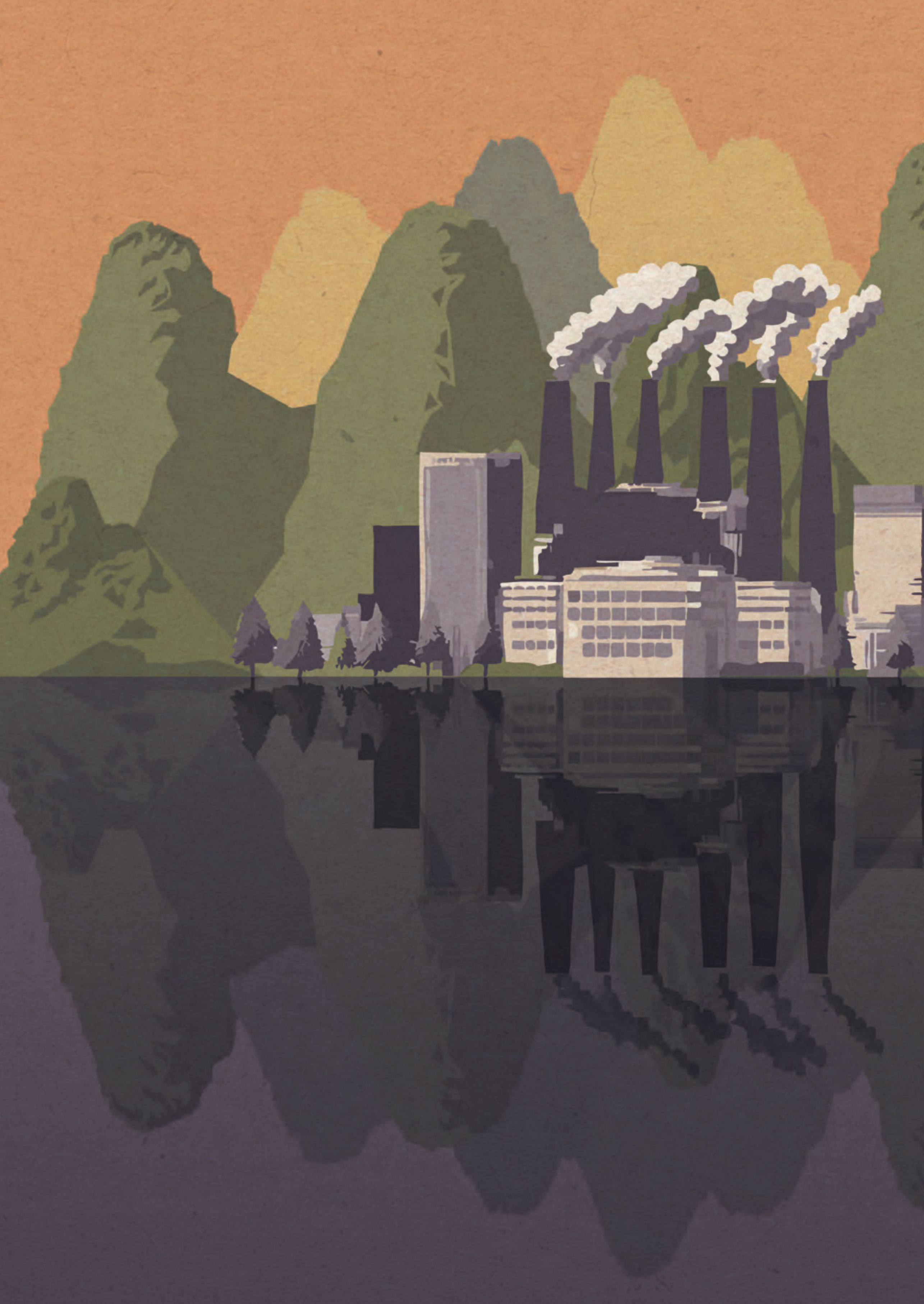
3.5. Conclusion

Despite widespread concerns regarding the sustainable exploitation of natural resources, the study shows that natural capital depletion may be a blessing in disguise. Studying a panel of 140 countries between 1990 and 2010, I find that natural capital depletion increases the rate of sustainable development, as measured by per capita Inclusive Wealth growth. The evidence is consistent with the idea that resource revenues are reinvested sufficiently into other types of capital assets. Human- and produced capital accumulation compensates for depleted natural capital, meaning that future generations have more rather than less productive assets to satisfy their economic needs. However, this is not the only interpretation consistent with the results. Natural resource-dependent economies could have a structural disadvantage, and depleting natural could mean their sustainable growth trajectories become 'less unfavorable'.

Remarkably, the average developed economy does not experience an increase in the rate of sustainable development when depleting natural capital. Although this may seem paradoxical, the outcome is quite sensible considering that developed economies face stronger diminishing returns to human- and produced capital accumulation.

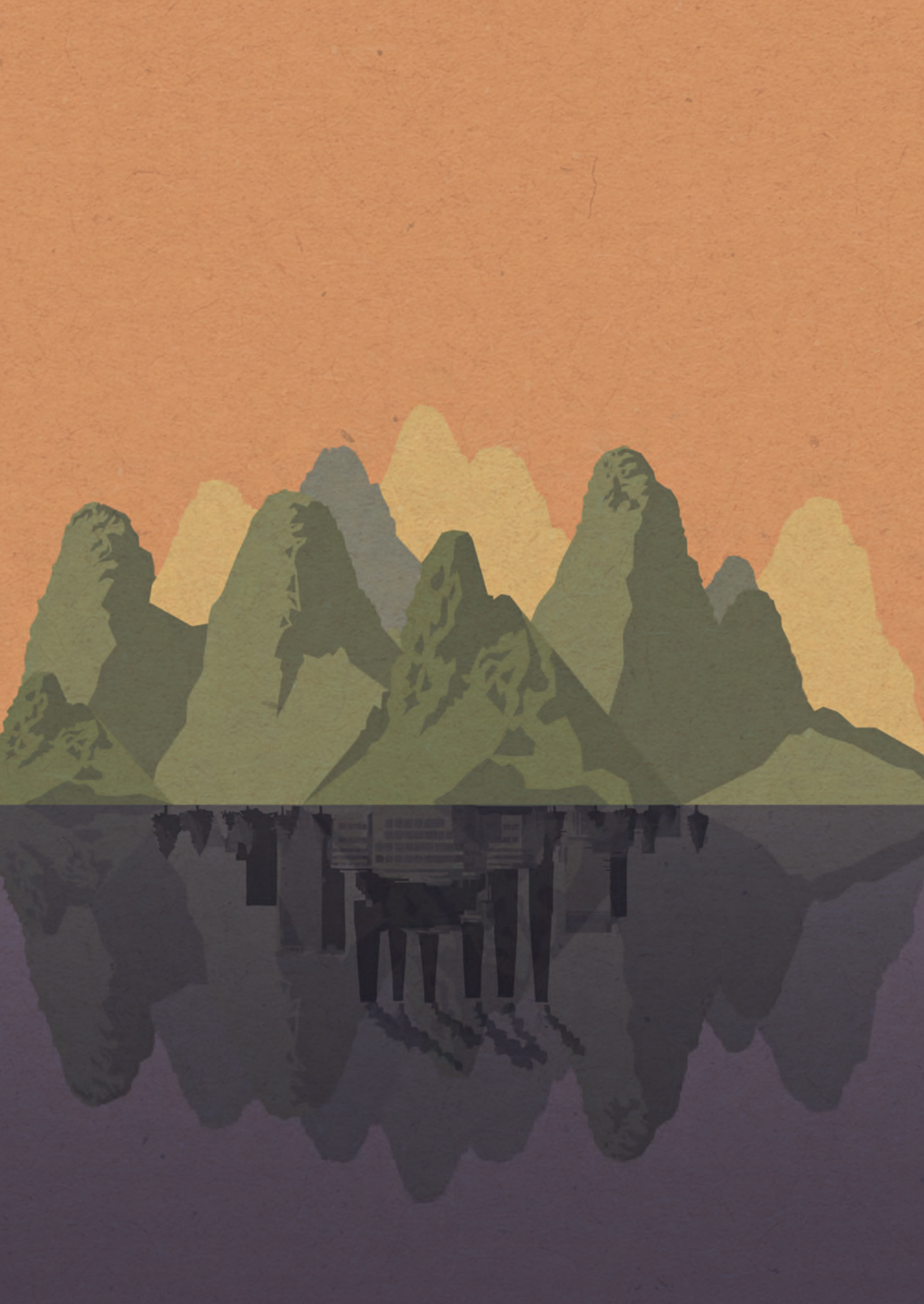
The policy implication is that natural capital management is not one-size-fits-all. Instead, countries sparse in human- and produced capital have a window of opportunity where reinvesting some depleted natural resources can potentially improve their sustainable development path. Due to its scarcity, the marginal benefits of human- and produced capital accumulation are still high, and the marginal cost of natural capital depletion is low. However, countries should be cautious in designing policies that rely on prolonged natural capital extraction. The potential gains become smaller and may even turn negative as human capital accumulates.

Several limitations apply. First, the study considers weak sustainable development and does not purport to comment on whether resource depletion is ecologically sustainable. Indeed, the depreciation of natural capital may foster economic health to the detriment of ecological health. Second, Inclusive Wealth accounting, the main data source and theoretical framework, remains a work in progress despite cutting-edge valuation methods. Although Inclusive Wealth offers the most comprehensive and advanced dataset on natural capital assets, the lack of point-source resource data in some countries may obscure the efficacy of the conclusions. I recommend quantifying and collating point-source natural resource-level data to further the understanding of the link between natural resources and sustainability.



Part 2

Unpacking natural resource conversion



Chapter 4.

The effect of natural resource rents, exports, and government resource revenues on Genuine Savings: Causal evidence from oil, gas, and coal

A previous version of this chapter is currently considered as a resubmission at the journal *World Development*. It was presented at the 2024 Dutch Environmental and Resource Economists annual conference and the 2022 annual conference of the European Society for Ecological Economics.

Abstract

This chapter studies how factors related to the process of natural resource conversion causally affect the rate of sustainable development as measured by Genuine Savings (GS). Some seminal studies on the relation between resource conversion and GS notwithstanding, a disaggregated examination of the role of the resource conversion process in sustainable development is lacking. I examine the effects of four stages of the conversion process—discovery, extraction, appropriation, and (re-)investments—on sustainable development. Empirically, I estimate the effects of four variables corresponding to these stages on Genuine Savings: natural capital, resource rents, resource exports, and government resource revenues. Results of an instrumental variable approach show causal effects of oil, gas, and coal rents (energy rents) and exports. These energy rents and exports jointly decrease GS, except in countries with good institutions. Additionally, economies dependent on energy exports appear to leverage their comparative advantage in the energy sector successfully, increasing GS. I conclude that policies for successful resource conversion should aim to improve institutional quality and reduce energy exports if a country has a comparative disadvantage in energy resources.

4.1. Introduction

It is theoretically possible for countries to use natural resources for sustainable development. The generalized Hartwick rule posits that natural resource exploitation can contribute to the well-being of current and future generations as long as its revenues are sufficiently converted into other forms of productive capital (Hamilton 1995). The idea is that reinvestments of resource revenues in human- and produced capital should offset the economic value lost from natural capital decline so that future generations inherit more per capita inclusive wealth rather than less. I call this process *natural resource conversion*: the process of transforming extracted natural resources into other capital assets so as to grow the total stock of capital assets and achieve sustainable development. The process of converting natural resources or resource conversion entails (1) prospecting and discovering natural resources, (2) extracting them, (3) appropriating the resource revenues, and finally (4) reinvesting/spending revenues to accumulate new capital. However, empirical studies on how the stages of natural resource conversion affect sustainable development are lacking.

Prior work studying the relationship between natural resources and sustainable development (e.g., Atkinson and Hamilton 2003; Bergougui and Murshed 2023; Boos and Holm-Müller 2013; De Soysa and Neumayer 2005; Dietz et al. 2007) has only considered one or two variables to approximate the entire conversion process. Furthermore, they use few control variables potentially leading to omitted variable bias as well as focus on cross-country correlations instead of causal relations. In contrast, this chapter studies empirically the conversion process at a more disaggregated level, considering all four stages simultaneously. It employs four natural resource variables: natural capital, natural resource rents, natural resource exports, and government natural resource revenues to pinpoint more accurately where sustainable development, the dependent variable, is fostered or hampered throughout the conversion process. Moreover, this chapter uses an instrumental variable approach to estimate causal effects for a large sample with a large vector of control variables.

Specifically, the empirical analyses of this chapter employ a dataset spanning 118 countries over 20 years (1998-2018). The key metric for sustainable development is Genuine Savings (GS). GS is an indicator of the net investment in physical, human, and natural capital. A country develops sustainably when its GS is positive, indicating a non-declining stock of total capital (Pearce and Atkinson 1993). GS is the default indicator of the sustainability of economic development (Cook and Davíðsdóttir 2021; Lindmark et al. 2018). It can measure future well-being over extended periods by tracking annual changes in a country's total capital stock (Greasley et al. 2014; Hanley et al. 2015). Therefore, the empirical analysis estimates (causal) effects of the four main independent variables on sustainable development measured by GS.

The remainder of the chapter is structured as follows. Section 4.2 describes the technical and economic background of the four stages of natural resource conversion before presenting hypotheses. Section 4.3 describes the data and method of empirical analysis. Section 4.4 presents the baseline results of the empirical analysis and its extensions. Section 4.5 discusses the key findings, limitations, and policy recommendations. Section 4.6 concludes.

4.2. Natural resource conversion: Stages, mechanisms, and relevant empirical indicators

Figure 4.1 presents a schematic overview linking the four stages of natural resource conversion to potential resource curses that can hamper sustainable development. Then, it links the stage-curse combination to the relevant empirical indicator for measuring countries' natural resources. Each variable, corresponding to a stage of the conversion process, approximates multiple behaviors and economic phenomena that can potentially benefit or harm sustainable development (i.e., resource blessings and curses, respectively). The so-called resource curse literature studying these economic behaviors and phenomena that hamper development is extensive. Various researchers have surveyed this literature (Deacon 2011; Frankel 2010; Gilberthorpe and Papyrakis 2015; Ross 2015; Van der Ploeg 2011; Van der Ploeg and Poelhekke 2016; Venables 2016), finding a wide array of resource curses, often overlapping. Badeeb et al. (2017) synthesized the survey outcomes using a *survey of surveys.* To be clear, however, I neither estimate empirically these curses directly, nor is the list of curses in Figure 4.1 and this section exhaustive. Instead, the section provides the economic background on what some consider to be the most potent curses associated with each stage. The remainder of this section discusses Figure 4.1's elements in more detail.

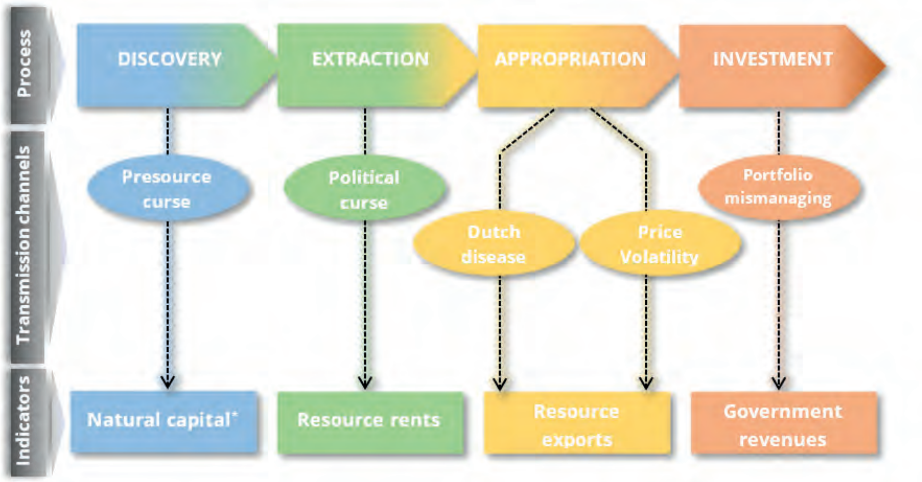


Figure 4.1. The four stages of natural resource conversion, their resource curses, and empirical indicators of countries' resource use

Notes: The figure connects the stages of the natural resource conversion process with the transmission channels of the resource curse and appropriate empirical indicators. The asterisk indicates that natural capital is not entirely able to measure the presource curse. Even though natural capital is positively associated with the discovery stage, other factors that jointly determine natural capital are not separated in current datasets.

4

4.2.1 Technical and economic background of the resource conversion process

4.2.1.1. Discovery: Exploration and (e)valuation

The first stage of the process, discovery, involves prospecting the available natural resources. The discovery phase provides an opportunity to gather information about potential future revenues, which can facilitate long-term planning (NRGI 2015). Initially, exploration uses techniques such as satellite and seismic imaging, as well as geophysical and geochemical surveys to identify potential areas with natural resources (Tordo 2010). The next step is to investigate promising areas more thoroughly by finding deposits and assessing the extraction's economic and technical feasibility. Once large quantities of natural wealth are mapped, the private and public sectors cooperate in developing strategies for sustainable exploitation. The discovery phase lasts until the exploration licenses expire and governments grant extraction licenses.

A short political horizon can prompt governments to underinvest in prospecting. Consequently, many African countries possess large unknown deposits of various natural resources (Collier and Laroche 2015). Moreover, companies benefit from underreporting discoveries. Large extraction and production (E&P) multinationals are typically involved from the beginning of the process and possess the sophisticated technical expertise to perform the exploration and extraction (Tordo et al. 2009). Countries' dependence on a few E&P multinationals can lead to an agency problem.

4.2.1.2. Extraction and production

The second stage entails extracting, producing, and monetizing natural resources (Henstridge and Roe 2018). This stage involves granting extraction licenses after exploration is completed. From a societal perspective, the government should allocate licenses that conform with national objectives to long-term partner companies with sufficient technical and financial capabilities. Private companies can negotiate contracts that deviate from applicable rules, laws, and regulations (NRGI 2015). Developing countries often lack the technical expertise and capital to extract natural resources. They depend on large E&P firms that are mostly foreign-owned, meaning these countries negotiate extraction contracts from a weaker bargaining position. Moreover, contract negotiations allow corruption to seep into the process and harm society while benefitting only an elite few (Collier and Laroche 2015).

The government can levy taxes, royalties, and other claims on the extractive company's sales or revenues (Henstridge and Roe 2018). A well-designed fiscal system is crucial for governments to guarantee adequate returns for their natural resources (Henstridge and Roe 2018; NRGI 2014). However, several factors affect the ability of governments to appropriate sufficient revenues. For instance, limited power and knowledge around taxing firms (e.g., royalties, production-sharing, income tax) and the assignment of extraction rights can compromise revenues. Furthermore, the appropriability of natural resources partially determines the ease of capturing the revenues (Boschini et al. 2007).[1] Hence, the extraction stage is crucial because it dictates the terms for appropriation.

1. New policy prescriptions are that countries without a comparative advantage can focus on natural resource extraction without exports. Even countries with modest-quality institutions can be on a sustainable development path if resource exports are minimized. Resource-rich economies with a comparative advantage should harness that benefit, as economies with sizable traded-energy sectors benefit sustainably. Accordingly, either minimizing or maximizing trade is a transitory solution while institutions gradually improve.

4.2.1.3. Appropriating revenues: Domestic consumption versus exports

In the third stage, national policies determine whether countries use natural resources for domestic production or exports. After extraction starts, how and where to sell resources remains a matter of national discretion (Tordo et al. 2009). Governments can exercise this discretion by directly influencing state-owned extraction companies or utilizing tax incentives. However, control over production quantities can vary significantly depending on the type of natural resource and the specific arrangement. For instance, countries that are part of OPEC may find their production levels influenced at the international level. Additionally, fluctuations in private companies' production levels, driven by the unpredictable nature of world resource prices in oil or mining resources, complicate appropriation. Thus, countries' circumstances determine their ability to appropriate rents (Tordo 2010).

4

4.2.1.4. Reinvestment of natural resource revenues

The fourth and last stage is investing the appropriated resource revenues in human and produced capital assets (Hamilton 1995). The contract terms established during the extraction stage can force the extracting company to make such investments. Thus, private resource-sector development can contribute to sustainable development. However, the government remains primarily responsible for infrastructure, schooling, health, and other human- and produced capital investments. It is paramount that governments collect and reinvest a sufficient share of resource tax revenues in the last stage (Collier and Laroche 2015; NRGI 2014). Government officials face the trade-off between allocating resource revenues toward reinvestments, benefitting future generations, or consumption, benefitting current generations. Long-term policy measures, such as a sovereign wealth fund, can align current- and future generations' well-being and to help navigate this trade-off (Ouoba 2020).

4.2.2. Transmission mechanisms

4.2.2.1. Presource curse

Discovery in the first stage of the natural resource conversion process can trigger the so-called *presource curse* (Katovich 2021). This phenomenon highlights the behavioral aspect of the resource curse, as new major resource discoveries generate expectations of future prosperity (Frynas and Buur 2020). However, these anticipations prove over-optimistic when the duration of extraction overruns, revenues are much lower than projected, and not all deposits prove commercially viable (Mihalyi and Scurfield 2021).

Nevertheless, governments enact policies over-optimistically, borrowing heavily in anticipation of rising GDP growth rates that never fully materialize (Cust and Mihalyi 2017). As a result, the government's fiscal capacity and governance quality erode, leaving a country not with the anticipated prosperity but with a lesser capacity to achieve sustainable development before extraction even begins.

4.2.2.2. The political resource curse

The second stage (extraction) can give rise to political resource curses. Ample empirical evidence shows that the presence of capturable resource rents causes corruption, rent-seeking, and erosion of political institutions (Ades and Di Tella 1999; Bhattacharyya and Hodler 2010; Brollo et al. 2013; Caselli and Michaels 2013; Caselli and Tesei 2016; James and Rivera 2022; Treisman 2000; Tsui 2011; Vicente 2010). Capturable rents incentivize political elites to engage in opportunistic behavior, stunting growth through legal and illegal activities. For example, Arezki and Brückner (2011) show that the presence of oil rents leads to corruption and a deterioration of political rights. The erosion of political institutions set in motion by resource endowments, mostly in non-democratic democracies, further exacerbates autocratic institutions (Caselli and Tesei 2016). This increases the power of interest groups, causes myopia within the political class, and further weakens political structures, policies, and institutions (Ross 1999).

Besides corruption, the political resource curse-umbrella contains legal activities such as rent-seeking behavior. This opportunistic behavior occurs when government agents collude with businesses seeking to limit competition instead of cooperating with businesses willing to engage in productive extraction practices (Mehlum et al. 2006, Van de Ploeg 2011). Rent-seeking implies that the most efficient party with the optimal terms for society does not receive natural resource contracts and licenses. Instead, government officials engage in grabbing behavior while rival political factions vie for control over resource revenues. This competition can result in impulsive, short-sighted decisions (Van der Ploeg 2011). It might incite faster resource extraction than is socially optimal. In the end, resource rents end up in the hands of unproductive private parties with a proclivity for squandering rather than sustainable investments (Papyrakis 2017). Competition over natural resources can also result in (violent) conflict (Vesco et al. 2020).

Besides corruption, rent-seeking, and conflict, resource-dependent countries are at risk of becoming rentier states (Isham et al. 2005). Their governments are highly dependent on natural resource revenues instead of taxation of the population. The citizenry under rentier states has fewer incentives to develop accountability mechanisms. Moreover, such governments can weaken dissent by financing patronage, targeted benefits, and other mechanisms using their resource revenues. Consequently, rentier state government's incentives are misaligned with the well-being of both current and future generations.

Whether through corruption (Kolstad and Søreide 2009; Mauro 1995), rent-seeking (Mehlum et al. 2006), rentier state effects (Isham et al. 2003), or conflict (Vesco et al. 2020), the presence of capturable resource rents can instigate various policy failures. They each lower income growth and reduce investments, ultimately hampering produced- and human capital accumulation. Although these mechanisms are associated most with the extraction stage of the resource conversion process, they are not exclusive to it. For example, evidence from Sao Tome and Principe shows that oil discoveries can fuel corruption, as seen in vote-buying practices and the opportunistic allocation of education scholarships (Vicente 2010).[2] Similarly, Caselli and Michaels (2013) find that increased government oil revenues do not translate into tangible development outcomes, hinting at the corruption of spending flows.[3] These instances suggest that corruption may also take place during the discovery and reinvestment stages, respectively.

4.2.2.3. Dutch disease and price volatility

In the third stage, appropriation, trade-related mechanisms may hinder sustainable economic development. Most literature considers these exogenous explanations of the resource curse; however, as will become clear, policy choices can underlie them. As before, the non-exhaustive mechanisms highlight the best-studied and relevant ones for explaining sustainable development.

First, the 'Dutch disease' describes the overvaluation of the national currency after a natural resource boom (Davis 1995) and an ensuing contraction of the traded sector (Corden and Neary 1982). Excessive resource exports lead to

2. Point-source resources, such as minerals, ores, and fossil fuels, are geologically concentrated and, therefore, more accessible economically than diffused resources such as timber and agriculture.
3. Vicente essentially uncovers a presource curse corruption mechanism, which I cannot measure empirically at the cross-country level. See discussion in Section 4.2.3.1.

an appreciation of the real exchange rate. This terms-of-trade deterioration leads to a reallocation of capital and labor away from the traded sector (i.e., resource movement effect). Additionally, the increase in income expands the non-traded sector (i.e., spending effect). Together, these effects lower the competitiveness of the non-resource traded sector (Badeeb et al. 2017; Gylfason 2001; Van der Ploeg 2011).

The decline in the traded sector can hamper sustainable development by causing lasting deindustrialization (Van der Ploeg 2011) and by lowering productivity gains from 'learning-by-doing' associated with the traded sector (Torvik 2001). Learning-by-doing describes the increasing returns via intersectoral spillovers that boost income. Deindustrialization lowers national investments. Consequently, excessive resource exports may lower countries' produced- and human capital investments—partially via income—and hurt sustainable development.

Second, the volatile nature of resource prices in the world market may hamper sustainable development. Van der Ploeg and Poelhekke (2009) argue that unanticipated output growth caused by volatile world resource prices lowers countries' income growth. The high-volatility nature of world resource prices, therefore, has an indirect hampering effect: it creates larger swings in output. This uncertainty discourages private and public parties from investing, making it challenging to plan economic development effectively (Badeeb et al. 2017; Savoia and Sen 2021). Governments face the challenge of adjusting and timing their savings to match the swings in income (Boos and Holm-Müller 2012). The reduction in national income and less effective economic planning hamper produced- and human capital investments. However, financialization (Van der Ploeg and Poelhekke 2009) and stabilizing sovereign wealth funds (James et al. 2022) attenuate the volatility curse.

Third, volatility may hamper human capital accumulation through labor market disruptions (Mousavi and Clark 2021). A resource boom (spike in resource world price) causes higher wages in the resource sector due to increased demand (Komarek 2016; Papyrakis and Raveh 2014). Assuming that non-resource sectors have higher human capital requirements than the resource sector, this lowers the wage premium for attaining higher levels of education, discouraging young people from staying in school (Cust and Poelhekke 2015).

A subsequent resource bust is unlikely to reattract this cohort back into school, leading to a permanent human capital loss.[4]

4.2.2.4. Portfolio mismanagement

In the last stage of the conversion process, reinvestments, portfolio mismanagement arises when resource-abundant governments underinvest resource revenues (Atkinson and Hamilton 2003). This mechanism describes the excessive allocation of revenues to government consumption (Collier and Laroche 2015). The revenues collected through natural resource taxation may lead governments to develop a false sense of financial security and relax fiscal discipline. Additionally, such governments might underestimate the importance of human capital accumulation and growth-friendly economic policies (Gylfason and Zoega 2006). High non-wage sources of income may imbue governments with a reduced need to diversify, weakening the incentive to invest in human capital. Ample empirical evidence finds a negative cross-country association between natural resource dependence and public education spending, supporting the idea of an underinvesting government (Cockx and Francken 2016; Gylfason 2001; Kim and Lin 2017).

Sovereign wealth funds can mitigate unsustainable spending practices of natural resource revenues (Ouoba 2020). A natural resource-based sovereign wealth fund can (i) allocate revenues to transfer wealth intergenerationally, (ii) fund investments in human, produced, and natural capital, and (iii) act as a stabilization measure against economic volatility (James et al. 2022). The former purposes (i and ii) address the looming risk of overconsumption in the short run, which hurts sustainable economic development as future generations receive insufficient total capital. The latter (iii) is a short-term solution to mitigate the price volatility curse during the appropriation phase of natural resource conversion. Portfolio mismanagement, as such, is not just a short-term policy failure. It signals a lack of structural policies to ensure sustainable reinvestments of natural resource revenues.

In contrast to the political resource curse mechanisms, portfolio mismanagement does not result from opportunistic behavior. Instead, government officials are myopic or less capable of economic planning for sustainable development. In this sense, portfolio mismanagement shares the

4. In the empirical approach, the dependent variable, Genuine Savings, considers expenditures on education and therefore cannot distinguish between investments (i.e., inputs) and tangible outcomes of human capital accumulation, which could hint at corruption.

behavioral element of myopia with the presource curse. The difference is the timing and the degree of uncertainty.

4.2.3. Empirical indicators of countries' resource use

The third row in Figure 4.1 links the empirical indicators of natural resources to the transmission channels. The purpose is to provide a central overview of the theoretical concepts and the empirical measures. Section 4.3 describes the operationalization of the data for the empirical analyses.

4.2.3.1. Natural capital

Natural capital is an imperfect, least-worst quantitative proxy describing the first stage of the resource conversion process. Natural capital indicates the economic value of all natural resources.[5] Natural resources, in turn, are all economically viable assets formed through natural processes, comprising non-renewable resources such as minerals and fossil fuels and renewable resources such as agricultural land, protected areas, and forests (Lange et al. 2018). Natural capital is not directly associated with any transmission channels.[6] Instead, it indicates potentially convertible economic value—the present value of future resource rents. Although previous studies find a positive association between natural capital and economic outcomes (Alexeev and Conrad 2009; Brunnschweiler and Bulte 2008; Cavalcanti et al. 2011; James 2015; Stijns 2005), I expect an omitted variable bias driving their findings. Economic outcomes materialize through exploitation, not abundance. Hence, using natural capital as a lone or second variable may cause it to absorb the effect of omitted variables that correlate with it. However, in this study's analysis, ceteris paribus, I expect that natural capital does not negatively or positively affect a country's rate of sustainable development.[7]

5. Arguably, resource booms increase resource rents leading to lower Genuine Savings by definition because resource rents are a subtractive component (Boos and Holm-Müller 2012). Although technically correct, it does not describe a source of economic inefficiency. Instead, it describes an accounting phenomenon. The empirical research design addresses this issue.
6. Bagstad et al. (2021) discuss specific metrics and methods to calculate the economic value and volumes of natural assets.
7. Stage one (prospecting and discovery) contains a process through which natural capital grows. Hence, an increase in natural capital can trigger a presource curse may. However, net changes in natural capital also include depletion, rendering the variable ambiguous.

4.2.3.2. Resource rents

Natural rents measure the economic value of resource production taking place during the extraction stage of the natural conversion process.[8] Specifically, resource rents refer to the value of resource production at world price minus their total cost of production, including a 'normal' return (Lebdioui 2021). What constitutes a normal return is contestable but typically comprises a return to labor, entrepreneurship, and capital. Resource rents are the residual or 'super profits' on top of these economic costs. Obtainable resource rents may give rise to political resource curses, such as corruption, rent-seeking, and more. The variable, therefore, proxies the net benefits of extraction minus the harmful effects of the political resources that take place during the extraction stage. More obtainable resource rents encourage such behaviors. Therefore, I expect higher levels of resource extraction to hamper sustainable development:

Hypothesis 1 Natural resource rents have a negative effect on a country's rate of sustainable development.

4.2.3.4. Resource exports

The third stage, appropriation, is best measured using natural resources exports. Most studies use resource exports (% of GDP) to measure natural resource dependence to approximate the aggregate effect of natural resource conversion on sustainable development (e.g., Bergougui and Murshed 2023; Boos and Holm-Müller 2013; Dietz et al. 2007). However, resource exports are a measure of vulnerability to trade-related resource curses. High resource exports increase exposure to resource price volatility and can cause a Dutch disease. Accordingly, the following hypothesis applies:

Hypothesis 2 Natural resource exports have a negative effect on a country's rate of sustainable development.

4.2.3.5. Government resource revenues

Government resource revenues are associated with the last stage of the conversion process. They measure the taxes, royalties, and other fees paid by extractive companies to governments. The larger the value, the more

8. The statement is non-falsifiable so not a true hypothesis. In principle, no-effect can be the alternative hypothesis, and a sufficiently small effect size could be taken as evidence to reject the null hypothesis. However, given that natural capital is likely subject to endogeneity (Van der Ploeg and Poelhekke 2010), its effect size cannot be interpreted confidently. Unfortunately, there are no valid and strong instruments for this variable at the cross-country level.

funds are available for human- and produced capital investments. However, these revenues present a dilemma for governments, especially those in resource-rich but income-poor nations. They face pressure to use resource revenues to immediately improve living standards and secure public trust rather than investing them in sustainable initiatives (Collier and Laroche 2015). Some literature suggests that the policy failure underlying the portfolio mismanagement mechanism may prevent adequate reinvestments. The key question is whether the expected positive relationship is sufficient to overcome the loss of natural resource depletion and damage from potential resource curses.

Hypothesis 3 Government natural resource revenues are positively associated with a country's rate of sustainable development.

I discuss the method for testing these hypotheses next.

4.3. Data and methods

4.3.1. Data and main variables

The panel comprises 77 countries from 1998 to 2018, with 1231 observations. An alternative panel employs 118 countries to maximize available observations as a sensitivity analysis. The World Bank Group (2023) World Development Indicators is the main data source. Table 4.1 presents descriptive statistics for all variables.

4.3.1.1 Dependent variable: Genuine Savings

The dependent variable is Genuine Savings (GS). It measures the net change in produced, human, and natural capital. The World Bank's (2023) Adjusted Net Savings (ANS) originally computes GS as follows:

$$GS(ANS) = \frac{GNS - D + CSE - R - CD}{GNI} \qquad \text{Eq. (4.1)}$$

where *GNS* indicates gross national savings to approximate produced capital accumulation, *D* indicates exogenous produced capital depreciation, *CSE* indicates current expenditure on education to approximate human capital investments, *R* indicates natural resource depletion, and *CD* indicates damages from carbon dioxide emissions. The indicator is operationalized as a percentage of Gross National Income (GNI) to scale the variable relative to a country's income, approximating its ability to save and therefore reinvest in capital assets.

Component *R* is the value of energy, mineral, and forestry rents within a year, which is exactly equal to independent variable resource rents. Hence, resource rents must have a direct negative impact on Genuine Savings by definition. However, I hypothesize there are also indirect effects—taking place during extraction—that lower Genuine Savings (Hypothesis 1). Therefore, I add *R* to the dependent variable to isolate these indirect effects. In doing so, I address Boos and Holm-Müller’s (2012) accounting issue that resource booms will have a negative effect on Genuine Savings by definition. Similarly, I add carbon dioxide damages to meet the exclusion restriction assumption for endogenous regressors (see Section 4.3.2.2). The final dependent variable becomes:

$$GS^{*} = \frac{GNS - D + CSE}{GNI} \qquad \text{Eq. (4.2)}$$

where GS^* indicates Genuine Savings without resource depletion and carbon dioxide damages. I sometimes refer to this variable as gross Genuine Savings because it omits the costs of resource rents. Conversely, net Genuine Savings subtracts resource rents. The variable is normally distributed and there are no outliers in the final sample.

4.3.1.2 Independent variables

4.3.1.2.1. Natural capital

The empirical analyses use four independent variables, each associated with a stage of the conversion process. The first independent variable is natural capital. It is operationalized as the natural logarithm of natural capital per capita provided by The Changing Wealth of Nations 2021 Report (World Bank Group 2022). Natural capital comprises the net present value of the future resource rents of forest, agriculture, minerals, fossil fuel, and fishery resources in constant dollars. To be complete, I expect no effect of natural capital on Genuine Savings but include it to estimate a comprehensive model.

Table 4.1. Descriptive statistics for all variables

	Mean	Std. dev.	Min	Max	Notes
Dependent variable					
Genuine savings (% of GNI)	25.3	10.5	-28.7	62.2	Adjusted Net Savings without natural resource depletion and CO2 damages (% of GNI) (World Bank Group 2023)
Independent variables					
Natural capital (real constant $, natural log, per capita)	8.62	0.782	6.64	11.7	Real dollar value of natural capital as provided by the Changing Wealth of Nations 2021 Report (World Bank Group 2022).
Total resource rents (% of GNI)	2.76	4.96	0	45.4	Residual value of natural resource production after subtracting average production costs (World Bank Group 2023)
Energy rents (% of GNI)	0.879	2.96	0	42.6	Residual value of oil, gas and coal production after subtracting average production costs (World Bank Group 2023)
Mineral rents (% of GNI)	0.437	1.24	0	14.2	Residual value of mineral production after subtracting average production costs (World Bank Group 2023)
Forestry rents (% of GNI)	1.44	3.76	0	41.4	Residual value of forestry after subtracting average production costs (World Bank Group 2023)
Resource exports (% of GNI)	5.90	7.39	0.024	77.2	Oil, gas, coal, mineral, ores, and agricultural goods export value (World Bank Group 2023)
Energy exports (% of GNI)	2.55	5.82	0	76.2	Oil, gas, and export value (World Bank Group 2023)
Mineral exports (% of GNI)	2.37	4.36	0.000	31.8	Minerals and ores export value (World Bank Group 2023)
Agricultural exports (% of GNI)	0.978	1.46	0.005	13.4	Raw agricultural material export value (World Bank Group 2023)
Government resource revenues (% of GNI)	0.268	1.02	0	16.6	Total natural resource taxation and non-tax revenues from Government Revenue dataset (UNU-WIDER 2023)
Instrumental variables					
Oil price instrument (real constant $)	58.7	270.6	0	3427.6	Average annual price based on monthly prices provided by commodity price dataset (i.e., Pink Sheet) multiplied by country average energy rents (World Bank Group 2023)
Gas price instrument (real constant $)	0.960	2.63	0	29.2	Average annual price based on monthly prices provided by commodity price dataset multiplied by country average energy rents (i.e., Pink Sheet) (World Bank Group 2023)

Table 4.1. Continued

	Mean	Std. dev.	Min	Max	Notes
Coal price instrument (real constant $)	12.4	33.8	0	308.2	Average annual price based on monthly prices provided by commodity price dataset multiplied by country average energy rents (i.e., Pink Sheet) (World Bank Group 2023)
Oil price volatility (annual std. dev.) instrument	20.4	63.7	0	1358.5	Oil price volatility, measured as the standard deviation of monthly prices provided by commodity price dataset multiplied by country average energy exports (i.e., Pink Sheet) (World Bank Group 2023).
Gas price volatility (annual std. dev.) instrument	2.06	5.26	0	98.7	Gas price volatility, measured as the standard deviation of monthly prices provided by commodity price dataset multiplied by country average energy exports (i.e., Pink Sheet) (World Bank Group 2023).
Coal price volatility (annual std. dev.) instrument	22.0	69.2	0	1464.9	Coal price volatility, measured as the standard deviation of monthly prices provided by commodity price dataset multiplied by country average energy exports (i.e., Pink Sheet) (World Bank Group 2023).
Control variables (time-varying)					
Produced capital (real constant $, natural log, per capita)	9.69	1.73	5.29	12.9	Real dollar value of produced capital as provided by the Changing Wealth of Nations 2021 Report (World Bank Group 2022).
Human capital (real constant $, natural log, per capita)	10.4	1.52	6.00	13.6	Real dollar value of human capital as provided by the Changing Wealth of Nations 2021 Report (World Bank Group 2022).
GDP (real constant $, natural log, per capita)	12.0	1.79	7.88	16.8	Gross Domestic Product per year corrected for PPP (constant 2017 dollars) from Penn World Table 10.1 (Feenstra et al. 2015)
Rule of law	0.091	0.909	-1.87	2.03	Scale between -2.5 and 2.5. Higher score is better rule of law. Provided by the Worldwide Governance Indicators (World Bank Group 2023)
Government effectiveness	.142	0.899	-1.55	2.16	Scale between -2.5 and 2.5. Higher score is better government effectiveness. Provided by the Worldwide Governance Indicators (World Bank Group 2023)
Control of corruption	0.044	0.947	-1.60	2.29	Scale between -2.5 and 2.5. Higher score indicates less corruption. Provided by the Worldwide Governance Indicators (World Bank Group 2023)

Table 4.1. Continued

	Mean	Std. dev.	Min	Max	Notes
Control variables (time invariant)					
Absolute latitude	27.3	17.5	1	62	Absolute value of countries' latitude (Ashraf and Galor 2013)
Population density in 1500	9.21	10.8	0.144	46.6	Population density in 1500 CE (Ashraf and Galor 2013)
Predicted genetic diversity	0.716	0.046	0.579	0.774	Scale 0-1, higher values indicate more predicted diversity (Ashraf and Galor 2013)
Continental orientation	1.63	0.693	0.5	3	Higher values indicate a more horizontal orientation (Ashraf and Galor 2013)
Number of domesticable animals	4.45	4.22	0	9	Absolute number of prehistoric domesticable animals in a country (Ashraf and Galor 2013)
Population in 1000 (natural log)	13.1	1.76	8.32	18.0	Natural log of the population in 1000 CE (Ashraf and Galor 2013)
Distance from the technological frontier in 1500 (natural log)	7.06	2.03	0	8.80	The natural log of 1 + the distance to the technological frontier in 1500 CE (Ashraf and Galor 2013)
Neolithic transition timing (natural log)	8.32	0.532	6.91	9.26	Natural log of the number of years since the neolithic transition happened. (Ashraf and Galor 2013)
Ancestry-adjusted years since agriculture (in thousands)	5.04	2.01	1.4	10.4	Number of years in thousands before year 2000, in thousands, that a substantial population living within what are the present country's borders began to obtain most of their calories from agriculture (Putterman and Weil 2010)
Timing of the use of plough	0.511	0.412	0	0.996	Number of years since the use of the plough for positive crops, scaled 0 to 1

Notes: The table presents the descriptive statistics for all variables used in the empirical analyses' main regressions. The sample comprises 1231 observations for all variables for 77 countries covering the period 1998 to 2018.

4.3.1.2.2. Resource rents

The second independent variable is natural resource rents, which aims to approximate the aggregate effects of resource blessings and curses that occur during the extraction stage, notably but not exclusively corruption and rent-seeking behavior. The World Bank (2023) provides comprehensive data on a country's natural resource rents, measured by the sum of oil, natural gas, coal, mineral, and forest rents. The research design comprises analyses using the aggregated measure (i.e., natural resource rents) and causal analyses using disaggregated resource rents (i.e., oil, gas, coal, mineral, and forest rents separately). The aggregated variable is never regressed simultaneously with the disaggregated variables, avoiding multicollinearity.

I operationalize resource rents and its disaggregated components as a percentage of GNI. As such, the coefficient indicates the proportion of capital accumulation resulting from natural resource extraction (e.g., b=1.1 indicates 1% of GNI more resource rents are associated with a 1.1% increase of produced- and human capital).

Because the dependent variable no longer subtracts resource rents, the coefficient for resource rents only reflects its impact on the capital accumulation component of GS. A coefficient of 1 implies that natural resource extraction leads to an equal accumulation of capital assets. A coefficient larger than 1 means that extraction results in positive net GS, and a coefficient less than 1 in negative net GS. Therefore, a coefficient below 1 supports Hypothesis 1, suggesting that political resource curses cause unsustainable extraction practices.

To address endogeneity, I use exogenous instruments for energy resource rents in the 2-stage least squares estimations. The instruments are country-weighted resource prices. The data come from the World Bank Commodity Price Data (i.e., the Pink Sheet). I discuss the rationale for the instruments in Section 4.3.2.2.

4.3.1.2.3. Resource exports

The third independent variable is natural resource exports, which I operationalize as a percentage of GNI. The World Bank (2023) provides data on energy, mineral, forestry, and agricultural exports. Akin to resource rents, I never regress the aggregated and disaggregated variables simultaneously and avoid multicollinearity. I use country-weighted resource price *volatilities*, provided by the Pink Sheet, as exogenous instruments for energy exports. Section 3.2.2 discusses the rationale for the instruments.

4.3.1.2.4. Government resource revenues

The final independent variable is government natural resource revenues. Natural resource revenues aim to approximate the aggregate effects of resource blessings and curses that occur during the spending/reinvestment stage. Data on government revenues from natural resources comes from the UNU-WIDER Government Revenue Dataset (GRD) (2023). I replace missing values with the difference between total revenue and total non-resource tax revenue per the authors' recommendations. The replaced values make a strong proxy (Prichard et al. 2018), demonstrated by a correlation of 0.91 between actual and predicted values for non-missing observations. The data is operationalized as a percentage of GNI.

4.3.1.3. Control variables

I use a range of control variables that determine countries' long-run development. Chapter 2 demonstrates increasing returns to produced- and human capital accumulation (Van Krevel 2023), which I control for using data from the Changing Wealth of Nations Report 2021 (World Bank 2022). National income, measured by per capita GDP (2017 constant $), determines the funds available for reinvestment into capital accumulation, which I take from the Penn World Tables 10.1 (Feenstra et al. 2015). Following the prior studies (Atkinson and Hamilton 2001; Bergougui and Murshed 2023; Dietz et al. 2007), I expect that institutional quality determines rates of Genuine Savings. Therefore, I use the rule of law and government effectiveness measures from the Worldwide Governance Indicators database (World Bank Group 2023). Additionally, I use its measure for control of corruption as a moderating variable in Section 4.4.3.

When applicable, the regressions include 11 time-invariant deep-determinant control variables such as absolute latitude, genetic diversity, and timing of the neolithic transition. Their data sources are discussed in Chapter 2. Table 4.1 (descriptive statistics) provides detailed information on these variables and their scales. Including time-invariant control variables reduces the sample from 118 countries and 1843 observations to 77 countries and 1231 observations. Consequently, the coefficients in the main analysis are less prone to an omitted variable bias but may be less representative. To be complete, I employ the full sample of 118 countries with fewer time-invariant controls in a sensitivity analysis in Section 4.4.4.

Table 4.2. below presents a complete overview of the correlations among the main independent variables.

Table 4.2. Pairwise correlation of main independent variables

	Natural capital	Resource rents	Energy rents	Mineral rents	Forest rents	Resource exports	Energy exports	Mineral exports	Agriculture exports	Resource revenues	Oil rent instrument	Gas rent instrument	Coal rent instrument
Resource rents	0.015												
Energy rents	0.294	0.593											
Mineral rents	0.128	0.254	-0.028										
Forest rents	-0.254	0.767	0.003	0.027									
Resource exports	0.443	0.462	0.663	0.346	-0.028								
Energy exports	0.389	0.485	0.878	-0.069	-0.030	0.768							
Mineral exports	0.182	0.115	-0.061	0.641	-0.012	0.569	-0.053						
Agriculture exports	0.149	0.061	0.032	0.115	0.016	0.301	0.054	0.102					
Resource revenues	0.176	0.469	0.725	0.109	0.01	0.539	0.617	0.084	0.014				
Oil rent instrument	0.250	0.559	0.918	-0.035	0.024	0.595	0.804	-0.070	0.012	0.732			
Gas rent instrument	0.213	0.168	0.399	-0.089	-0.064	0.378	0.434	0.052	0.028	0.147	0.248		
Coal rent instrument	0.045	-0.002	0.066	0.165	-0.109	0.148	0.012	0.233	0.005	0.129	-0.012	0.143	
Energy volatility instrument	0.315	0.427	0.763	-0.070	-0.015	0.617	0.805	-0.050	0.060	0.583	0.740	0.436	0.015

Notes: The table presents pairwise correlation among main independent variables of the main sample of 77 countries and 1231 observations. Correlations in italics indicate variables that do not appear simultaneously in the second-stage regressions of the baseline analyses. The high correlation between energy exports and rents does not appear to cause multicollinearity issues (VIF < 10).

4

4.3.2. Empirical approach

4.3.2.1. The model

The correlational analyses use pooled OLS with robust standard errors clustered at the country level. The main analyses use a 2SLS approach with clustered-robust errors. The main benefit of OLS and 2SLS is that they measure between-country variation to indicate the level effects of independent variables on GS. For example, I expect that natural capital has no (level-)effect on GS. However, natural capital depreciation—corresponding closely with extraction—is expected to have a negative effect on GS (see Chapter 3). A between-country approach is necessary to estimate level-effects of independent variables. The downside is a potential bias due to omitted unobserved time-invariant factors. I minimize this risk with our large vector of control variables.

Country-fixed effects (FE) capture all observed and unobserved time-invariant determinants of Genuine Savings, reducing the risk of omitted variable bias. However, it also means the coefficients show their within-country or change effects, which, as noted earlier, may not adequately capture our theoretical understanding of the independent variables. To be complete, I present and discuss both between-country (OLS/2SLS) and within-country (FE/2SLS-FE) results. Accordingly, Equation 4.3 below describes the model:

$$GS^{*}_{it} = \beta_0 + \beta_1 NC_{it} + \beta_2 R_{it} + \beta_3 E_{it} + +\beta_4 G_{it} + \mathcal{Z}_{it} + T_t + (\alpha_i) + \varepsilon_{it} \qquad \text{(Eq. 4.3)}$$

for country *i* at time *t*, where is the robust error term clustered at the country level. GS^* is gross Genuine Savings as a percentage of GNI. The remaining variables in the equation reflect the four independent variables. *NC* is the natural log of natural capital per capita; *R* is the value of natural resource rents as a percentage of GNI; *E* is natural resource exports as a percentage of GNI; *G* is government resource revenues as a percentage of GNI; $Z_{i,t}$ includes the vector of control variables; and T_t and α_i indicate the time and country fixed effects.

4.3.2.2. Identification strategy

The main independent variables potentially suffer from endogeneity. Accordingly, I use an instrumental variable approach to address endogeneity for natural resource rents and exports. Unfortunately, although natural capital and government resource revenues may also suffer from endogeneity (Van der Ploeg and Poelhekke 2010), I cannot construct instruments for these variables using the following approach.[9]

The identification strategy follows previous studies to create instruments for natural resource rents and exports (e.g., Acemoglu et al. 2013; Lyatuu et al. 2021), in the tradition of shift-share instruments (Bartik 1991). The idea is to decompose the endogenous variable into an exogenous share, used by the instrument, and an endogenous share, which I eliminate. A country's natural resource rents in a given year depend on the price and the quantity of extracted natural resources. The quantity may result from policies that also affect Genuine Savings (% of GNI), leading to endogeneity. Alternatively, a decrease in national income (GNI) could incentivize governments to increase resource extraction, leading to simultaneity bias. Hence, resource rents and resource exports are endogenously determined. Shift-share instruments exploit the exogenous part of the variable (world resource prices) as variation for causal identification.

Specifically, I multiply the countries' average oil, gas, and coal rents (% of GNI) by the relevant global resource price per year. Similarly, I instrument energy exports using the country-average percentage of oil, gas, and coal exports (% of GNI) multiplied by their annual price volatilities. The logic is that price fluctuations disproportionally affect those that heavily extract and export energy resources. Hence, I leverage exogenous resource price changes impact resource rents differently, depending on their long-term resource production structures. Essentially, I follow Acemoglu et al. (2013) by stating that resource prices influence their rents (i.e., super profits over costs), which, in turn, affect the funds used for education expenditures and produced capital investments.

The exclusion restriction assumption is met if resource prices only affect Genuine Savings through the natural resource conversion process. Gross GS has three components: education expenditure, produced capital accumulation,

9. Data on production volumes would be ideal but are unavailable for a large cross-section of countries for many years. Moreover, the correlation between available production data (e.g., World Mining Data; Reichl et al. 2021) and resource rents is near-perfect at 0.97.

and produced capital depreciation.[10] The latter is widely considered exogenous. Resource prices and changes cannot affect produced or human capital accumulation beyond the conversion process. For example, when resource price changes hurt incomes in the non-resource sector, it falls under the scope of the Dutch disease, measured using the resource exports variable. Therefore, I am confident in meeting the exclusion restriction principle.

The instruments for resource rents meet the relevance condition. In the complete baseline 2SLS analyses (Table 4.4, Models 9 and 10), the instruments for energy rents prove strong with a partial R^2 of 0.662 and an F-statistic of 59.3, surpassing the conventional thresholds of 0.1 and 10, respectively. The instruments for energy exports, derived from oil, gas, and coal price volatility, also exceed these thresholds (F-stat 61.4, partial R^2 of 0.499). Although including fixed effects lowers these diagnostics, they remain firmly above the thresholds, confirming that the relevance condition is met. Full diagnostics for each estimation are reported at the bottom of the relevant tables. Appendix 4A, Table A1 presents first-stage estimations.

4.4. Results

4.4.1. Between- and within-country correlations: OLS and FE estimates

Table 4.3 presents the OLS and FE results for the main sample. Models 1 and 3 exclude the independent variables linked to hypotheses to show the explanatory power of the control variables. It shows that the control variables and time-fixed effects explain 31.4% of the between-country variation in Genuine Savings (GS). Model 3 adds the main independent variables. It finds that government resource revenues are positively associated with the between-country variation GS. I cannot reject the null hypothesis for the other explanatory variables. The lack of a statistically significant coefficient for natural capital is as expected. For natural resource rents, it is also consistent with Hypothesis 1. Without any political resource curses, the coefficient of

10. Carbon dioxide damages from fossil fuel consumption was originally a component of GS and may decrease directly when resource prices increase. The removal of CO2 damages eliminates a potential violation of the exclusion restriction principle. To be complete, I verify that removing CO2 damages does not change the dependent variable substantially. The correlation with and without CO2 damages is over 0.99; and regression coefficients are virtually identical.

resource rents should be equal to or greater than 1. A coefficient less than 1 indicates that natural resource extraction lowers net GS.

Government revenues' coefficient of 4.03 indicates that a country with 1% of GNI higher government revenues on average has roughly 4% of GNI higher Genuine Savings. Although governments reinvests of resource revenues in the last stage of the conversion process seems remarkably productive, two caveats apply. First, potential endogeneity from simultaneity biases this coefficient upward. Second, the between-country estimates may omit unobserved time-invariant confounders beyond the large vector of controls.

Model 4 includes country-fixed effects to account for these unobserved factors, lowering the coefficient of government resource revenues. Every additional natural resource tax dollar spent only increases GS by 0.75 cents instead of by four dollars. Whether this large discrepancy results from the difference between within- and between-country estimations or by including unobserved time-invariant factors is unknown.[11] Additionally, Model 4 finds a positive coefficient for natural resource rents, suggesting that as countries extract more natural resources, their higher gross GS increases (ignoring depletion as a component of GS). The coefficient of 0.359 suggests it falls short of fully compensating for the loss of natural capital, consistent with Hypothesis 1.

11. The difference between within- and between country variation concerns a theoretical difference between level and change effects. In this context, a government with more natural resource revenues can convert each dollar of resource revenues into four times more produced- and human capital (on average), while additional dollar of resource revenues only accumulates three quarters of a dollar worth of produced and human capital.

Table 4.3. Baseline OLS estimation: Effects of stages of the natural resource conversion process on Genuine Savings

	Dependent variable: Genuine Savings (% of GNI)			
	(1)	**(2)**	**(3)**	**(4)**
	Model with controls only (OLS)	Model with controls only (FE)	Model with all explanatory variables (OLS)	Model with all explanatory variables (FE)
Independent variables				
Natural capital (natural log, per capita)	-	-	1.60 (1.72) [p=0.356]	2.01 (1.87) [p=0.286]
Resource rents (% of GNI)	-	-	-0.031 (0.18) [p=0.862]	0.359 (0.18) [p=0.050]
Resource exports (% of GNI)	-	-	-0.029 (0.16) [p=0.856]	0.005 (0.12) [p=0.965]
Government resource revenue (% of GNI)	-	-	4.03 (0.75) [p=0.000]	0.750 (0.348) [p=0.034]
Time-varying control variables				
Produced capital (natural log, per capita)	-0.514 (2.39) [p=0.830]	-1.08 (2.48) [p=0.665]	-2.77 (1.79) [p=0.125]	-0.863 (2.77) [p=0.756]
Human capital (natural log, per capita)	2.07 (2.06) [p=0.318]	-2.31 (2.68) [p=0.392]	1.86 (1.98) [p=0.350]	-2.36 (2.60) [p=0.368]
Per capita GDP (natural log, per capita)	1.29 (1.50) [p=0.392]	10.4 (3.40) [p=0.003]	2.09 (1.30) [p=0.113]	10.4 (3.30) [p=0.022]
Rule of law	1.97 (3.14) [p=0.532]	-4.23 (1.61) [p=0.010]	2.88 (2.82) [p=0.310]	-3.69 (1.58) [p=0.022]
Government effectiveness	0.029 (2.42) [p=0.991]	1.99 (1.43) [p=0.169]	0.327 (2.45) [p=0.894]	2.08 (1.49) [p=0.166]
Time invariant control variables	Yes	N/A	Yes	N/A
Time fixed effects	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes
N	1231	1231	1231	1231
#-countries	77	77	77	77
R^2 (within)	0.314	0.109	0.441	0.166

Notes: Robust standard errors are clustered at the country level in parentheses. The p-values are reported in square brackets. Time-fixed effects are per year. The time-invariant controls are colinear with fixed effects in Model 2 and 4. R^2 applies to Models 1 and 3, R^2 within applies to Models 2 and 4.

4.4.2. Causal evidence of between- and within-country effects: 2SLS and 2SLS-FE estimations

Table 4.4 presents the baseline 2SLS regressions using exogenous instruments for energy rents and energy exports (% of GNI). Other natural resource rents (mineral and forest), exports (mineral and raw agricultural goods), natural capital, and government resource revenues are not instrumented and, therefore, potentially suffer from endogeneity. The discussion focuses on instrumented endogenous regressors.

Models 5, 7, and 9 present the between-country 2SLS analyses when rents, exports, and both are instrumented, respectively. Models 6, 8, and 10 present the equivalent 2SLS with country-fixed effects (FE) regressions that estimate within-country variation. Instrument weakness warrants caution when interpreting the coefficients of regressions with only one endogenous regressor (Models 5-8). The instruments for Models, 9 and 10, are very strong.

A key result is that energy rents (% of GNI) increase net Genuine Savings in between- and within-country estimations. An increase in oil, gas, or coal extraction causes a disproportionate increase in GS because the coefficient is larger than 1. The implication is that energy extraction positively contributes to GS net of depreciation.

Conversely, energy exports (% of GNI) have a negative causal effect on GS. A one percent increase in energy exports leads to a 0.4 to 1.2 percent decrease in GS, depending on within- or between-country variation. The finding is consistent with Hypothesis 2, predicting that the Dutch disease and resource price volatility cause resource curses hamper countries' ability to develop sustainably.

To put the main results in perspective, Table 4.5 presents Model 9 and Model 10's standardized coefficients. Based on between-country estimates, a one standard deviation increase in energy rents (% of GNI) leads to a 6.72 increase in gross Genuine Savings (% of GNI). In comparison, a one standard deviation increase in energy exports (% of GNI) leads to a 6.99 decrease in gross GS (% of GNI). The effects of more energy extraction and exports roughly cancel out because the in-sample correlation between energy exports and rents is very high (0.88, Table 4.2). Consequently, extracting and exporting energy resources does not lead to human and produced capital accumulation and lowers net GS, which subtracts the costs of energy depletion.

Table 4.4. Two-stage least square estimation: Energy exports and energy rents as endogenous variables

	Dependent variable: Genuine Savings (% of GNI)					
	(5)	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
	2SLS	**2SLS-FE**	**2SLS**	**2SLS-FE**	**2SLS**	**2SLS-FE**
Instrumented independent variables						
Energy rents (% of GNI)	1.14 (1.12) [p=0.311]	1.91 (1.07) [p=0.073]	-	-	2.27 (1.29) [p=0.080]	1.44 (0.688) [p=0.036]
Energy exports (% of GNI)	-	-	-0.856 (0.620) [p=0.167]	0.160 (0.316) [p=0.613]	-1.20 (0.628) [p=0.056]	-0.418 (0.142) [p=0.003]
Independent variables						
Natural capital (natural log, per capita)	1.60 (1.78) [p=0.372]	2.20 (2.01) [p=0.275]	2.60 (1.99) [p=0.191]	1.88 (2.00) [p=0.346]	2.58 (2.06) [p=0.212]	2.16 (1.99) [p=0.277]
Energy rents (% of GNI)	-	-	1.38 (1.06) [p=0.192]	0.024 (0.365) [p=0.947]	-	-
Mineral rents (% of GNI)	0.514 (0.367) [p=0.161]	0.502 (0.300) [p=0.094]	0.287 (0.377) [p=0.447]	0.367 (0.288) [p=0.202]	0.251 (0.378) [p=0.506]	0.458 (0.302) [p=0.130]
Forest rents (% of GNI)	-0.144 (0.189) [p=0.445]	0.302 (0.268) [p=0.261]	-0.184 (0.187) [p=0.327]	0.316 (0.269) [p=0.240]	-0.187 (0.191) [p=0.328]	0.302 (0.267) [p=0.259]
Energy exports (% of GNI)	-0.515 (0.427) [p=0.228]	-0.543 (0.345) [p=0.115]	-	-	-	-
Agricultural exports (% of GNI)	-0.481 (0.389) [p=0.216]	-0.285 (0.328) [p=0.384]	-0.521 (0.394) [p=0.186]	-0.054 (0.244) [p=0.824]	-0.535 (0.393) [p=0.174]	-0.225 (0.292) [p=0.441]
Mineral exports (% of GNI)	0.080 (0.189) [p=0.674]	0.297 (0.159) [p=0.062]	0.089 (0.186) [p=0.634]	0.291 (0.153) [p=0.057]	0.107 (0.188) [p=0.568]	0.295 (0.158) [p=0.061]
Government resource revenue (% of GNI)	3.18 (1.54) [p=0.038]	-0.481 (1.39) [p=0.730]	3.81 (0.893) [p=0.000]	0.864 (0.484) [p=0.074]	3.15 (1.50) [p=0.035]	-0.020 (1.50) [p=0.989]
Time-varying control variables						
Produced capital (natural log, per capita)	-3.14 (1.79) [p=0.079]	0.322 (2.79) [p=0.908]	-3.41 (1.84) [p=0.064]	-1.21 (2.68) [p=0.652]	-3.53 (1.84) [p=0.055]	-0.016 (2.66) [p=0.995]
Human capital (natural log, per capita)	2.62 (1.93) [p=0.176]	-2.09 (2.51) [p=0.405]	2.91 (1.97) [p=0.139]	-2.88 (2.60) [p=0.269]	3.05 (1.96) [p=0.120]	-2.24 (2.54) [p=0.379]

Table 4.4. Continued

	Dependent variable: Genuine Savings (% of GNI)					
	(5)	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
	2SLS	**2SLS-FE**	**2SLS**	**2SLS-FE**	**2SLS**	**2SLS-FE**
Per capita GDP (natural log, per capita)	1.90 (1.26) [p=0.133]	8.36 (3.47) [p=0.016]	1.89 (1.23) [p=0.125]	11.1 (3.37) [p=0.001]	1.72 (1.26) [p=0.171]	8.93 (3.34) [p=0.007]
Rule of law	2.67 (2.85) [p=0.349]	-3.99 (1.64) [p=0.015]	2.31 (2.83) [p=0.414]	-3.60 (1.61) [p=0.025]	2.55 (2.90) [p=0.380]	-3.95 (1.64) [p=0.016]
Government effectiveness	0.140 (2.49) [p=0.955]	2.30 (1.45) [p=0.113]	0.100 (2.58) [p=0.969]	2.39 (1.46) [p=0.102]	0.007 (2.70) [p=0.998]	2.30 (1.45) [p=0.111]
Time invariant control variables	Yes	N/A	Yes	N/A	Yes	N/A
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	Yes	No	Yes	No	Yes
Cluster robust F stat first stage (rents)	6.46	8.04	-	-	59.3	11.5
Cluster robust F stat first stage (exports)	-	-	36.9	20.2	61.4	37.4
Partial R2 first stage (rents / exports)	0.434	0.155	0.182	0.040	0.662 / 0.499	0.149 / 0.056
Hansen statistic	2.135 [p=0.344]	1.660 [p=0.436]	0.739 [p=0.691]	1.908 [p=0.385]	1.349 [p=0.853]	2.398 [p=0.663]
R2 (within)	0.450	0.129	0.433	0.166	0.393	0.164
#-countries	77	75	77	75	77	75
N	1231	1229	1231	1229	1231	1229

Notes: Robust standard errors are clustered at the country level in parentheses. The p-values are reported in square brackets. Time-fixed effects are per year. The time-invariant controls are colinear with fixed effects when applicable. Endogenous energy rents are instrumented with the average energy rents by country multiplied by the average resource price (i.e., oil, gas, or coal) for that year. Endogenous energy exports are instrumented with the average energy exports by country multiplied by the resource volatility (i.e., oil, gas, or coal) for that year. Table 4.7 repeats models 9 and 10 with the full sample of 118 countries and fewer time-invariant control variables. First stages are presented in Appendix 4A, Table A1.

Table 4.5. Standardized coefficients for main causal effects

Dependent variable: Genuine Savings (% of GNI)	Model 9 (between-country causal effects)	Model 10 (within-country causal effects)
Energy rents coefficient (regular / standardized)	2.27 / 6.72 [p=0.080]	1.44 / 4.27 [p=0.036]
Energy exports coefficient (regular / standardized)	-1.20 / -6.99 [p=0.056]	-0.418 / -2.44 [p=0.003]

Notes: The table presents the regular coefficient of energy rents (% of GNI) and energy exports (% of GNI) from Model 9 and 10 in Table 4.4. Their standardized coefficients are in brackets. P-values are reported in square brackets.

However, the effect on net GS is zero when relying on within-country evidence. Model 10's standardized coefficient for rents is larger than the absolute standardized coefficient for energy exports (4.27 > |-2.44|). The unstandardized difference of approximately 1 suggests that additional energy extraction and exports have no effect on net GS. Hence, the average country can benefit from energy extraction and domestic use of the resources.

Other types of natural resource rents and exports correlate neither positively nor negatively with Genuine Savings. The null-result of natural capital is found again, consistent with expectations. Government resource revenues only have a statistically positive association in the full model without fixed effects, which may be biased upward.

4.4.3. Corruption during the extraction phase: A moderation analysis

I introduce the moderating variable *control of corruption* from the World Bank (2023), scaled from -2.5 to 2.5 and subsequently standardized. A high value indicates better control of corruption, thus less corrupt governments. I interact this variable with resource rents in Model 11 and energy rents in Models 12 and 13. The interaction shows how corruption—one outcome of the political resource curse—during the extraction stage alters the effect of resource rents on Genuine Savings. I expect that more control of corruption increases the coefficient of resource rents, indicating that extraction increases GS more than when control of corruption is low.

Table 4.6 reports the results of the interaction analysis using the OLS, 2SLS, and 2SLS-FE estimates. The 2SLS regressions interact an exogenous variable (control of corruption) with the endogenous energy rents variable. To achieve this accurately, I interact the instruments with control of corruption in the first stage and use both energy rents and the interaction between rents and control of corruption as endogenous variables in the second stage.

Results show a positive between-country coefficient of the interaction variable in Models 11 and 12, indicating that natural resource rents have a more positive effect on GS in countries with better control of corruption. Figure 4.2 illustrates the effect sizes. In a country two standard deviations above the mean level of control on corruption, increasing resource extraction by one standard deviation increases GS by approximately 5% (of GNI). Conversely, the effect is negative (-2.5%) for countries two standard deviations below the mean control of corruption.

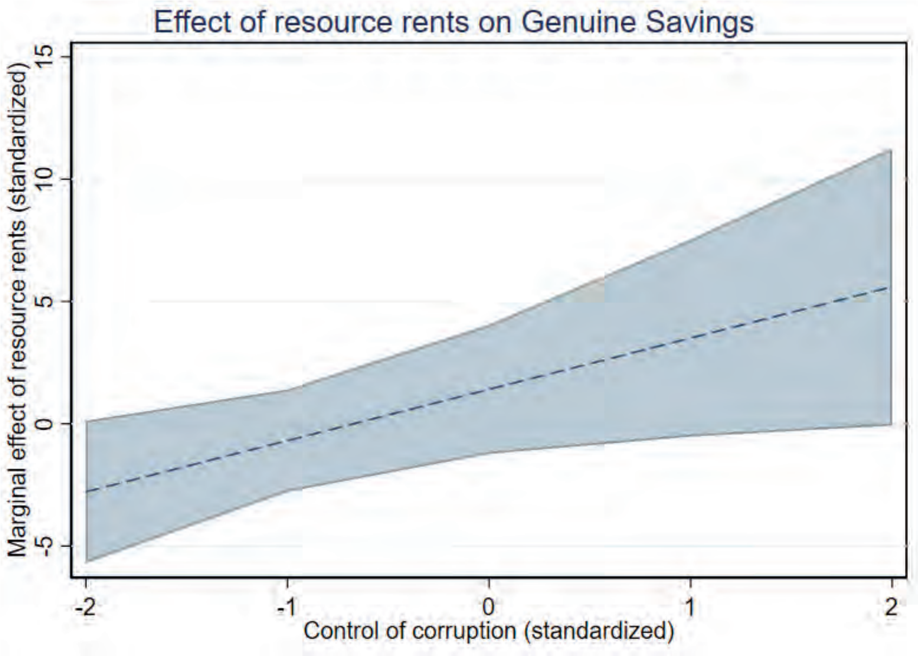


Figure 4.2. Plot of interaction between control of corruption and resource rents

Notes: The figure presents the interaction effect between control of corruption and natural resource rents. Both variables are standardized. The figure is based on the estimations in Table 4.6, Model 11, using the OLS approach for the main sample.

However, the OLS estimates amplify the true interaction effect. The 2SLS analysis in Model 12 shows the interaction variable's standardized coefficient is less than half of the OLS estimate in Model 11. Energy rents have a positive effect on GS in all countries, albeit the effect is larger in countries with little corruption (~10% of GNI) compared to those with significant corruption (~6% of GNI). Only the least corrupt countries achieve positive net GS from energy extraction because the standardized coefficient of energy exports is -7.94. Hence, corruption during extraction is an important inhibitor of natural resource conversion. Achieving positive net GS requires excellent institutions, low energy exports, or both.

Table 4.6. Interaction analysis: The moderating effect of corruption on the relationship between resource rents and Genuine Savings

	Dependent variable: Genuine Savings (% of GNI)		
	(11)	**(12)**	**(13)**
	Model interacts natural resource rents with control of corruption (OLS)	**Model interacts energy rents with control of corruption (2SLS)**	**Model interacts energy rents with control of corruption (2SLS-FE)**
Interaction variable			
Resource rents (% of GNI, standardized) * Control of corruption (standardized)	2.10 (1.10) [p=0.060]	-	-
Energy rents (% of GNI, standardized) [instrumented] * Control of corruption (standardized)	-	0.948 (0.571) [p=0.096]	0.635 (0.573) [p=0.267]
Instrumented independent variables			
Energy rents (% of GNI, standardized)	-	8.23 (4.11) [p=0.045]	4.03 (1.70) [p=0.018]
Energy exports (% of GNI)	-	-1.36 (0.64) [p=0.032]	-0.445 (0.203) [p=0.029]
Independent variables			
Control of corruption (standardized)	-1.69 (2.53) [p=0.506]	-3.87 (2.53) [p=0.126]	0.489 (1.18) [p=0.678]
Natural capital (natural log, per capita)	0.973 (1.74) [p=0.578]	2.37 (2.11) [p=0.261]	2.12 (2.03) [p=0.296]
Resource rents (% of GNI) (standardized)	1.41 (1.59) [p=0.377]	-	-
Mineral rents (% of GNI)	-	0.223 (0.376) [p=0.553]	0.414 (0.291) [p=0.155]
Forest rents (% of GNI)	-	-0.232 (0.179) [p=0.196]	0.294 (0.268) [p=0.272]
Resource exports (% of GNI)	-0.046 (0.159) [p=0.773]	-	-
Agricultural exports (% of GNI)	-	-0.517 (0.398) [p=0.194]	-0.184 (0.270) [p=0.495]

Table 4.6. Continued

	Dependent variable: Genuine Savings (% of GNI)		
	(11)	**(12)**	**(13)**
	Model interacts natural resource rents with control of corruption (OLS)	**Model interacts energy rents with control of corruption (2SLS)**	**Model interacts energy rents with control of corruption (2SLS-FE)**
Mineral exports (% of GNI)	-	0.142 (0.186) [p=0.443]	0.296 (0.157) [p=0.060]
Government resource revenue (% of GNI)	4.25 (0.737) [p=0.635]	3.40 (1.52) [p=0.026]	0.532 (1.22) [p=0.663]
Time-varying control variables			
Produced capital (natural log, per capita)	-2.51 (1.78) [p=0.163]	-3.63 (1.82) [p=0.046]	-0.068 (2.65) [p=0.980]
Human capital (natural log, per capita)	2.18 (1.84) [p=0.241]	3.24 (1.85) [p=0.080]	-2.15 (2.58) [p=0.404]
Per capita GDP (natural log, per capita)	1.73 (1.31) [p=0.188]	1.46 (1.24) [p=0.240]	8.85 (3.38) [p=0.009]
Rule of law	4.22 (3.48) [p=0.230]	5.14 (3.45) [p=0.137]	-4.17 (1.69) [p=0.013]
Government effectiveness	1.23 (2.58) [p=0.635]	1.53 (2.63) [p=0.561]	2.11 (1.57) [p=0.178]
Time invariant control variables	Yes	Yes	N/A
Time fixed effects	Yes	Yes	Yes
Country fixed effects	No	No	Yes
Cluster robust F stat first stage (rents)	-	47.5	29.1
Cluster robust F stat first stage (exports)	-	83.5	25.1
Cluster robust F stat first stage (interaction term)	-	1284.1	229.4
Partial R2 first stage (rents, exports, interaction)	-	0.673 / 0.512 / 0.827	0.158 / 0.070 / 0.301
Hansen statistic	-	4.848 [p=0.563]	4.275 [p=0.640]
R^2 (within)	0.449	0.383	0.178
#-countries	77	77	77
N	1231	1231	1231

Notes: Robust standard errors are clustered at the country level in parentheses. The p-values are reported in square brackets. Time-fixed effects are per year. Endogenous variables are instrumented using a multiplication of country-averages and resource price levels per year and a multiplication of country averages and resource price levels per year. Control of corruption is an exogenous variable. The interaction between corruption and natural resource rents is endogenous. The instruments are the direct ones used in previous analyses and their interactions with control of corruption.

4

4.4.4. Sensitivity analysis: Expanding sample size

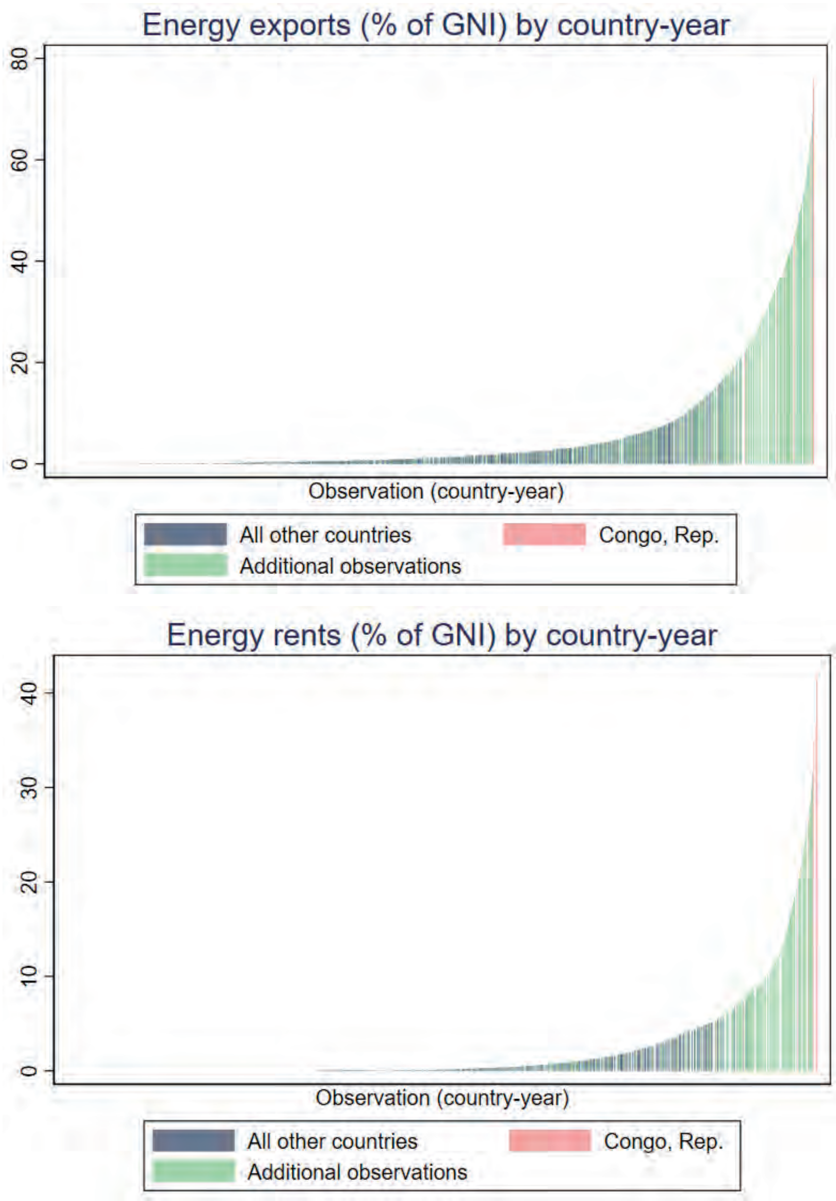


Figure 4.3. Additional observation values for energy rents and energy exports

Notes: The figure illustrates the values of the additional observations when increasing the sample size. Notably, additional observations have much higher energy rents and energy exports on average, Congo, Rep. notwithstanding.

The main sample comprises 77 countries with complete data, expandable to 118 countries with limited control variables due to missing data. There is a trade-off between the estimated model's completeness and the sample's comprehensiveness. The main analyses opt for completeness to optimize the accuracy of the between-country estimates. However, I perform a sensitivity analysis using the expanded sample. The analysis' between-country estimates may be less precise but improve country coverage, especially with high values of main independent variables (see Figure 4.3). Descriptive statistics for the expanded sample are presented in Appendix 4B, Table B1.

Table 4.7 presents the results. Energy rents maintain a statistically significant positive coefficient throughout all models except for Model 16 (2SLS with limited controls and expanded sample).[12] Hence, even though I find a positive effect of resource extraction, the evidence is weaker in the expanded than the main sample. Moreover, the effect size of approximately 1 in Model 18 suggests that energy extraction, ceteris paribus, has a net-zero effect on net Genuine Savings for the average country.

Energy exports have a negative effect on GS in the main sample (Models 14, 15, and 17), but not in the expanded sample (Models 16 and 18). The difference stems from cross-country heterogeneity. Constructing a third sample of only the additional observations and regressing GS on endogenous energy exports and rents ($N = 524$, $R^2 = 0.469$) finds positive effects of energy rents (0.942, $p=0.043$) and energy exports (0.464, $p=0.055$).[13] Hence, energy exports have a negative effect in one group of countries and a positive effect in another.

Average energy exports are substantially higher among additional observations than in the main sample (11.9 > 2.55, % of GNI). The difference suggests that the benefits of energy exports increase as the traded energy sector is larger. This result contradicts Hypothesis 2, which predicts that more resource exports invite vulnerability to trade-related resource curses. Comparative advantage in the energy sector can potentially explain the positive effect of energy-abundant-exporting countries.

Finally, I do not find robust evidence that government resource revenues increase or decrease Genuine Savings. Natural capital's between-country

12. The effect reemerges when excluding energy exports.

13. Results are not displayed in any tables. All time-varying controls and country-fixed effects are included.

Table 4.7. Sensitivity analysis: Two-stage least square estimations with expanded sample but fewer control variables

	Dependent variable: Genuine Savings (% of GNI)				
	2SLS (between-country)			2SLS-FE (within-country)	
	(9/14)	(15)	(16)	(10/17)	(18)
	Main sample (original)	Main sample (limited controls)	Full sample (limited controls)	Main sample (original)	Full sample
Instrumented independent variables					
Energy rents (% of GNI)	2.27 (1.29) [p=0.080]	2.23 (1.17) [p=0.056]	0.406 (1.09) [p=0.710]	1.44 (0.688) [p=0.036]	1.02 (0.463) [p=0.028]
Energy exports (% of GNI)	-1.20 (0.628) [p=0.056]	-1.01 (0.552) [p=0.069]	0.377 (0.497) [p=0.448]	-0.418 (0.142) [p=0.003]	0.335 (0.214) [p=0.118]
Independent variables					
Natural capital (natural log, per capita)	2.58 (2.06) [p=0.212]	1.97 (1.71) [p=0.251]	-1.06 (0.806) [p=0.190]	2.16 (1.99) [p=0.277]	3.29 (1.36) [p=0.015]
Mineral rents (% of GNI)	0.251 (0.378) [p=0.506]	0.200 (0.391) [p=0.609]	1.052 (0.447) [p=0.019]	0.458 (0.302) [p=0.130]	0.549 (0.261) [p=0.035]
Forest rents (% of GNI)	-0.187 (0.191) [p=0.328]	-0.255 (0.173) [p=0.139]	-0.347 (0.188) [p=0.065]	0.302 (0.267) [p=0.259]	0.319 (0.274) [p=0.244]
Agricultural exports (% of GNI)	-0.535 (0.393) [p=0.174]	-0.270 (0.426) [p=0.527]	-0.202 (0.485) [p=0.677]	-0.225 (0.292) [p=0.441]	-0.191 (0.275) [p=0.487]
Mineral exports (% of GNI)	0.107 (0.188) [p=0.568]	0.101 (0.192) [p=0.600]	0.032 (0.169) [p=0.849]	0.295 (0.158) [p=0.061]	0.166 (0.157) [p=0.291]
Government resource revenue (% of GNI)	3.15 (1.50) [p=0.035]	2.66 (1.73) [p=0.124]	0.356 (0.357) [p=0.320]	-0.020 (1.50) [p=0.989]	-0.106 (0.200) [p=0.596]
Time-varying control variables					
Produced capital (natural log, per capita)	-3.53 (1.84) [p=0.055]	-2.52 (1.75) [p=0.149]	-0.296 (1.41) [p=0.834]	-0.016 (2.66) [p=0.995]	-1.08 (2.23) [p=0.628]
Human capital (natural log, per capita)	3.05 (1.96) [p=0.120]	2.16 (1.97) [p=0.272]	1.07 (1.80) [p=0.555]	-2.24 (2.54) [p=0.379]	-2.68 (1.90) [p=0.159]
Per capita GDP (natural log, per capita)	1.72 (1.26) [p=0.171]	1.91 (1.29) [p=0.141]	0.685 (0.724) [p=0.344]	8.93 (3.34) [p=0.007]	9.98 (2.71) [p=0.000]

Table 4.7. Continued

	Dependent variable: Genuine Savings (% of GNI)				
	2SLS (between-country)			2SLS-FE (within-country)	
	(9/14)	(15)	(16)	(10/17)	(18)
	Main sample (original)	Main sample (limited controls)	Full sample (limited controls)	Main sample (original)	Full sample
Rule of law	2.55 (2.90) [p=0.380]	1.56 (2.91) [p=0.593]	0.050 (2.38) [p=0.983]	-3.95 (1.64) [p=0.016]	-1.11 (1.42) [p=0.433]
Government effectiveness	0.007 (2.70) [p=0.998]	1.82 (2.64) [p=0.491]	3.53 (2.05) [p=0.085]	2.30 (1.45) [p=0.111]	1.22 (1.29) [p=0.345]
Time invariant control variables	All	Few	Few	N/A	N/A
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	No	No	Yes	Yes
Cluster robust F stat first stage (rents)	59.3	44.3	45.2	11.46	11.36
Cluster robust F stat first stage (exports)	61.41	65.1	106.9	37.37	13.46
Partial R2 first stage (rents, exports)	0.662 / 0.499	0.680 / 0.522	0.569 / 0.662	0.149 / 0.056	0.229 / 0.196
Hansen statistic	1.349 [p=0.853]	1.691 [p=0.792]	2.380 [p=0.666]	2.398 [p=0.663]	3.051 [p=0.549]
R^2 (within)	0.407	0.369	0.419	0.164	0.217
#-countries	77	77	110	77	115
N	1231	1231	1760	1229	1840

Notes: Robust standard errors are clustered at the country level in parentheses. The p-values are reported in square brackets. Time-fixed effects are per year. The time-invariant controls are colinear with fixed effects when applicable. Endogenous energy rents are instrumented with the average energy rents by country multiplied by the average resource price (i.e., oil, gas, or coal) for that year. Endogenous energy exports are instrumented with the average energy exports by country multiplied by the resource volatility (i.e., oil, gas, or coal) for that year. Model 9/14 is identical to Model 9 from Table 4.4. Model 10/17 is identical to Model 10 from Table 4.4. Limited time-invariant control variables are absolute latitude, predicted genetic diversity, population in 1000 CE, and ancestry-adjusted years since agriculture (in thousands).

estimates (Models 14, 15, and 16), which present its level effect, are consistent with the predicted null-effect on GS.

4.5. Discussion

4.5.1. Key findings

The relationship between natural resource exploitation and sustainable development measured by Genuine Savings (GS) is more complex than previously considered. Accounting for the four-stage natural resource conversion process, our empirical analyses find several factors fostering and hampering sustainable development. In contrast to previous studies, resource abundance (i.e., natural capital) alone does not explain why most resource-rich economies develop unsustainably. Evidence from between-country analyses is consistent with a null-effect. The analysis suggests that GS is affected via natural resource extraction, appropriation, or reinvestments.

During the extraction phase, countries with very low-quality institutions experience declining GS, **supporting Hypothesis 1**. Conversely, countries with good institutions convert energy resources into human- and produced capital and achieve positive GS. Thus, institutional quality emerges as an important determinant of countries' success in extracting energy resources in an economically sustainable manner.

During the appropriation stage, the causal effect of energy exports on Genuine Savings is predominantly negative, **supporting Hypothesis 2**. Lower GS from energy exports may stem from vulnerability to resource price volatility and the Dutch disease. Countries with strong institutions can overcome these negative effects on GS. The combined effect of energy extraction and exports on GS is positive in these countries. For most, however, the combined effect is negative.

However, energy exports do not always hamper economic sustainability. I find a positive effect of energy exports in countries with a sizable traded-energy sector. These countries successfully leverage their comparative advantage in the energy sector for sustainable development.

Finally, approximating the spending/(re-)investment phase, government resource revenues are positively associated with Genuine Savings, **supporting**

Hypothesis 3. However, the result is sensitive to model specifications and may suffer from endogeneity.

4.5.2. Policy recommendations

Natural resource exploitation lowers Genuine Savings in most countries. However, countries with well-functioning institutional safeguards overcome political resource curses to achieve sustainable economic development. For others, the necessary institutional reforms are infeasible in the short run. At the same time, mineral-rich countries now face a window of opportunity to leverage their resources for sustainable development. Countries such as The Gambia, Ghana, and the Democratic Republic of Congo possess significant mineral deposits that will be in high demand during the various green transitions. These countries must find preemptive measures to prevent opportunistic behavior such as rent-seeking, corruption, and patronage.

A key obstacle is the ability to negotiate fair and transparent agreements prioritizing human- and produced capital investments instead of short-term gains for elites. Currently, it is standard to first grant exploration licenses before negotiating extraction licenses. Alternatively, countries should consider negotiating extraction contracts and designing spending policies before exploration efforts begin. Then, extraction rates and reinvestment schemes—possibly using sovereign wealth funds (James et al. 2022)—operate independently of politics and discoveries. Achieving this requires overcoming the monopsony power of large extraction companies through international cooperation (Slack 2012). Initiatives such as the Extractive Industry and Transparency Initiative (EITI) and the Natural Resource Governance Institute (NRGI) can play a crucial role by setting industry standards and mediating negotiations.

4.5.3. Limitations

Our study cannot detect the so-called presource curse in a large sample despite state-of-the-art data. Country-level data on natural capital only reports net depletion from discoveries and extraction which cannot be disentangled.

Government natural resource revenues, one of the main variables, may suffer from endogeneity. Its values are determined by the policies and institutions that also affect Genuine Savings. Ideally, one uses an instrumental variable that strongly and exogenously determines natural resource tax revenues. However, in a cross-country setting, I am unaware of such instruments.

Moreover, while consistent, the UNU-WIDER GRD (2023) dataset is not complete and comprises rough approximations. This study's estimates for government resource revenues, therefore, warrant cautious interpretations.

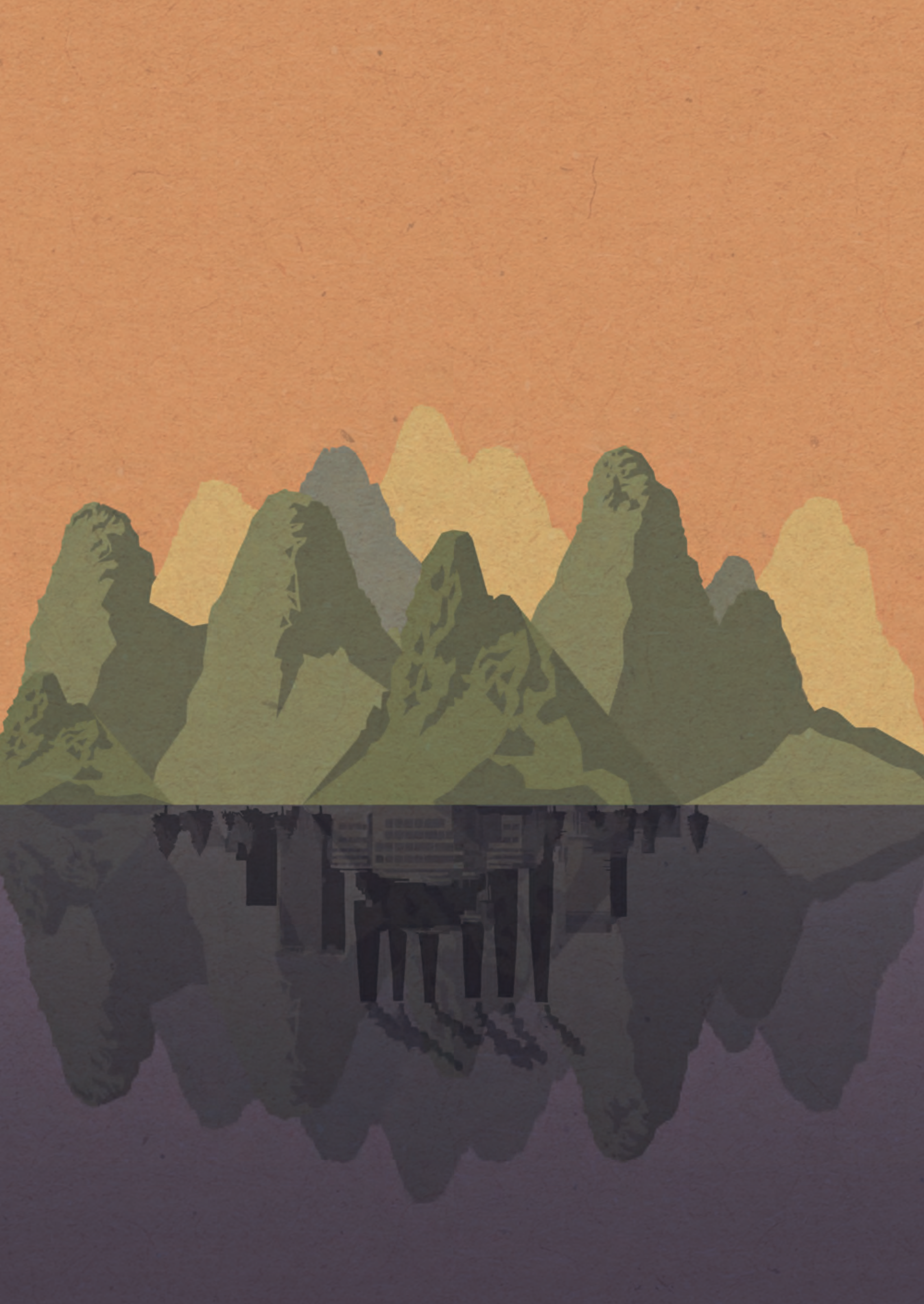
Future research requires precise instruments and indicators for natural resource discoveries and tax revenues. The latter should be decomposed by revenue type (tax, royalty, fee, and other), resource type, and company. Disaggregating these data enables closer and more robust examinations of the fourth and final stage of the natural resource conversion process.

4.6. Conclusion

This study provides a nuanced understanding of the relationship between natural resource exploitation and weak sustainable development as measured by the World Bank's Genuine Savings (GS) indicator. I empirically estimate the effects of variables associated with the four stages of natural resource conversion: discovery, extraction, appropriation, and reinvestment. As such, I analyze more accurately how resource exploitation fosters and hampers sustainable development. I draw lessons from causal evidence on energy resource exploitation. These are the following:

1. energy extraction has a positive causal effect on GS except in countries with poor institutions,
2. energy exports have a negative causal effect on GS,
3. energy extraction and exports have a joint negative effect on GS in most countries except ones with solid institutions, and
4. energy exports have a positive causal effect in countries with high energy exports, suggesting successful utilization of comparative advantage.

In contrast to previous studies, these findings lay out multiple routes to sustainable economic development through natural resource exploitation. Corroborating previous studies, high-quality institutions mitigate resource curses and foster economic sustainability. However, developing robust institutions takes time and effort. In the meantime, resource-rich economies seek immediate sustainable uses of their natural wealth.



Chapter 5.

How do natural resource revenue windfalls affect public service spending? Causal evidence from Indonesian regencies

This chapter was presented at the 2024 International PhD Workshop on Sustainable Development workshop at Columbia University New York, The United States of America, KVS New Paper Session 2023 in The Hague, The Netherlands, and the 2023 EAERE Natural Resources and Development workshop in Ascona, Switzerland.

Abstract

Natural resource revenues contribute to sustainable development when they are reinvested sufficiently in public services such as education that offer long-term social returns. Cross-country studies suggest that resource-rich countries underinvest, spending disproportionally less on public services than non-resource-rich countries do. However, these macro-studies typically suffer from endogeneity problems, hampering clean identification of the causal effect of resource richness on public service spending. This chapter exploits plausibly exogenous temporal fluctuations in natural resource tax revenues to assess if natural resource revenue windfalls crowd out public spending that fosters sustainable development. The sample comprises 130 Indonesian regencies that receive fees and royalties from resource exploitation in nearby areas but exert no control over prices and production volumes, as well as 138 control regencies. The results indicate that local governments spend resource revenues productively. For instance, 36% of natural resource revenue windfalls are spent on education (on average), which is more than the share of local tax revenues or central government funds that regencies spend on education. When considering the broad range of government expenditures, the analysis suggests a proclivity among politicians to use windfalls for sustainable public investments rather than short-term consumption. Thus, I conclude that natural resources can contribute to sustainable development via public service spending.

5.1. Introduction

Although natural resources can bring economic opportunities to developing countries, it is unclear how natural resource revenues affects the public spendings that contribute to sustainable development. To develop sustainably, resource-rich countries must reinvest natural resource revenues into other forms of capital, which can be achieved via public service spending. Public spending on human capital—such as education—is especially important. Education is a key source of long-term development (e.g., Barro 1991; Erosa et al. 2010; Gennaioli et al. 2013) and is primarily funded by governments. Hence, this chapter studies the relationship between natural resources and public service spending. Specifically, I analyze the causal effect of natural resource revenue windfalls on the various spending categories that contribute to sustainable development.

Most cross-country studies find a relationship between natural resource-richness and sustainable development (e.g., Boos-Holm-Müller 2012; Bergougui and Murshed 2023). Potentially underlying this relationship, several studies observe an inverse association between an economy's resource dependence and spending on education and healthcare (Cockx and Francken; 2014; Cockx and Francken, 2016; Gylfason, 2001; Mousavi and Clark, 2021; Papyrakis and Gerlagh, 2004; Turan and Yanıkkaya, 2020). They propose the crowding out hypothesis, suggesting that governments spend insufficient resource revenues on public service that contribute to human capital accumulation. Unfortunately, econometric issues plague these studies (Van der Ploeg and Poelhekke 2017). The main problem is endogeneity. For example, an explanatory variable used in previous studies—the share of natural wealth in total wealth—is endogenous with regard to both education and development. Hence, we cannot be sure their estimates are reliable, as they are likely biased. Addressing this critical limitation requires an empirical strategy that enables clean causal identification.

This study uses Indonesian regencies—a low-level administrative unit—as a case study for investigating natural resources revenue windfalls' causal effect on public service spending. Revenues from oil and gas extraction are shared with other regencies in their province. Roughly 25% of regencies do not extract these fossil fuels themselves but receive fees and royalties from resource extraction that occurs in nearby regencies. These resource revenues are exogenous. Regencies cannot affect their oil and gas revenues, as they respond only to changes in world prices, external production volumes, or the inter-regency revenue reallocation scheme. The sharing policy has not changed over the years, and regencies are so small that they are international oil and gas price-takers. Moreover, non-producing regencies exert no control over production volumes outside their jurisdiction. Limiting the analysis to non-producing regencies therefore assures triple exogeneity of revenue flows.

Although geology determines a near-constant extraction rate per single oil well, international oil price peaks are associated with substantially more oil drilling.[1] Therefore, oil production volumes, and by extension, oil royalties and fees, may not be truly exogenous in producing regencies. Only non-producing regencies meet all three criteria of exogeneity.

I use a panel of 268 non-producing regencies between 2008 and 2017, 130 of which receive plausibly exogenous resource revenue windfalls. This panel combines subnational fiscal expenditures from the SKID database by the Indonesian Ministry of Finance (2021) with oil and gas production facilities data from the ESDM database by the Indonesian Ministry of Energy and Mineral Resources (2021). I distinguish locally-produced oil and gas revenues from shared oil and gas revenues by intersecting sites with regency boundaries, which identifies regencies with exogenous oil and gas revenue fluctuations. The main analysis uses a two-way fixed effect Spatial Autoregressive Regression (SAR) model. I first consider the causal effect of resource revenue windfalls on public education spending before expanding the analysis to consider all expenditure functions of local governments.[2]

The baseline results indicate that oil and gas revenues increase education spending more than proportionally. Oil and gas windfall spending on education surpasses even the share of local taxes spent on education. This finding challenges the common belief that local governments spend local tax revenues more on important public services than natural resource revenues (Gadenne 2017). Until now, extant evidence finds that governments squander natural

1. Katovich et al. (2023) show for Brazil that oil discoveries rise substantially during price booms, meaning that oil property right-holders increase production volumes at will, albeit with a lag. My sample period contains episodes of oil price volatility, meaning that opportunistic regencies may produce additional oil and gas (revenues) in subsequent years, rendering government revenues a potentially endogenous variable.
2. As a robustness test, I use a geographical regression discontinuity design as an alternative approach to causal identification (Appendix 5D).

resource rents (Brollo et al. 2013; Paler 2013). However, this chapter's results indicate this does not hold for Indonesian local governments.

Further results indicate that resource windfalls are spent comparatively more on public services associated with sustainable development (i.e., education, health, the environment, and capital assets) than on public services associated with current well-being. The results imply that local policymakers prioritize the use additional funds for sustainable goals over the immediate needs of their citizens. An exception is the increased spending on social security, an expenditure function associated with current well-being, following a windfall. Although there is some heterogeneity among Indonesian regencies, nearly all of them appear to prioritize funding public investments when considering how to spend natural resource tax windfalls.

An important implication of this study is that natural resource abundance is not necessarily a curse for long-run development. Instead, local government spending can facilitate sustainable development by investing resource revenues in human capital. This finding is particularly relevant for resource-rich countries that possess abundant mineral resources and are in a window of opportunity. As the world transitions towards a low-carbon future, the demand for their natural wealth will increase sharply. These countries could benefit by using the resource revenues to diversify their economies.

The study also makes an important contribution to the literature. It provides novel evidence that resource revenues can have a positive causal effect on public investments such as education, health, and the environment. Therefore, the study complements the shift in the resource curse literature, refocusing on subnational settings for cleaner empirical analyses (Cust and Poelhekke 2015; Manzano and Gutiérrez 2019). For instance, studies at the subnational level also find that resource exploitation fosters regional income (Arellano-Yanguas 2019; Cust and Rusli 2015; Hilmawan and Clark 2019; Loayza and Rigolini 2016) and development outcomes (Caselli and Michaels 2013; Mamo et al. 2019; Wegenast et al. 2020).

The rest of this chapter is organized as follows. Section 5.2 provides background information on the Indonesian institutional context. Section 5.3 describes the data and empirical strategy, Section 5.4 discusses the results for education, and Section 5.5 includes all expenditure functions. Section 5.6 concludes.

5.2. Research context: Intergovernmental revenue transfers and public service provision in Indonesia

Indonesia is a developing economy rich in several types of natural resources. Indonesia's administrative division contains many layers. There are 34 provinces, divided into more than 500 regencies, each with local governments, subdivided into districts. Whereas this governance structure was of lesser importance prior to 2001 due to authoritarian rule, a decentralization policy came into effect that transferred fiscal (Law 25/1999), political, and administrative (Law 21/1999) authority to local governments. Before this process, the central government was the primary actor and financier of the public sector. The decentralization policy rapidly transferred responsibilities for public services such as infrastructure, health, and education from the central government to regencies, leapfrogging the provincial administrations. Indonesian regencies inherited both fiscal- and revenue-raising responsibilities simultaneously.

By 2001, most regencies applied for autonomy. Consequently, local government budgets shift from being financed almost exclusively by the central authority to receiving funds from central tax revenues (DAU) and locally generated revenues (DBH). While the funds from the central authority (DAU) still constitute the lion's share of local government's budgets, a notable change is that they become general grants instead of earmarked funds. The regency leaders gain authority and management of such funds and could enact local finance provisions and regulations (Law 25/1999). The self-raised revenues (DBH) consist of resource revenues and royalties from the extraction of natural resources (DBH Sumber Daya Alam) and local taxes (DBH Pajak). Additionally, the central authority provides special allocation funds (DAK) to support national priorities.[3] Even though the number of national priorities expanded, DAK's share in local government's budgets remains modest (~5%).

3. For instance, national priorities can be infrastructure and environment projects but also comprise aid to regencies in lagging provinces, such as additional support for education spending.

Table 5.1. Natural resource revenues allocation scheme

	Before 2001			After 2001			
Resource	**Central**	**Province**	**Regency**	**Central**	**Province**	**Regency**	
			Producing			**Producing**	**Non-prod**
Oil	100	0	0	84.5	3.1	6.2	6.2
Gas	100	0	0	69.5	6.1	12.2	12.2
Mining	65 / 30	19 / 56	16 / 14	20 / 20	16 / 16	6.4 / 32	0 / 32
Forestry	50	30	15	20	16	32	32

Notes: All numbers are percentages. Mining reports the allocation of rents and royalties on the dash's left and right. (Olsson and Valsecchi 2015, based on World Bank and Law 25/1999 sources)

The 2001 big-bang decentralization introduces a natural resource revenue-sharing scheme, summarized in Table 5.1. The central government retains a lower percentage of natural resource tax revenues while resource-exploiting regencies gain a greater percentage. For oil and gas revenues, provincial and regency governments go from 0 percent to 3.1 and 6.2 percent of tax revenues, respectively. Moreover, non-producing regencies within a producing province are entitled to a share of natural resource tax revenues. For instance, 6.2 percent of the oil revenues are distributed among non-producing regencies in a producing province. Thus, many regencies collect natural resource tax revenues from exploitation over which they exert no control—outside their jurisdiction.

As a result, local politicians in producing regencies directly control local taxes (e.g., territory and building taxes, property taxes, and to a lesser extent, personal income taxes) and indirectly control revenues raised through natural resource exploitation. The producing regency government holds most natural resource property rights and can greenlight extraction, influencing its natural resource tax revenues. Central revenue (DAU) depends on several criteria, such as the fiscal need (e.g., population size, regional GDP, area) and a base allocation to cover spending on personnel. Regency government debt is allowed but remains relatively small at 0.2% of GDP. Furthermore, it requires pre-approval from the central government and is legally capped at 75% of the previous year's total revenues. Accordingly, politicians have a limited ability to abuse subnational debt to raise public spending temporarily for reelection purposes, which could confound the empirical analysis.

The public service responsibilities of Indonesian regencies include public works, healthcare, education, cultural and social affairs, labor, environmental protection, land, citizenship, and investments. Aside from uncategorized expenditures, education is the largest public service spending category, followed by health at some distance (OECD 2021). Regency education spending pays for teacher and administrator salaries, school programs, and other activities. Special allocation funds (DAK) finance specific programs that reduce regional education differences with oversight from the central government. Hence, local politicians can choose where and how much to spend on education in their jurisdiction.

Law 13/2006 categorizes public spending. For example, *Public Service* concerns programs that support the functioning of governments (e.g., salaries for administrators). *Economy* entails a wide range of services for and towards business, but also some investments in infrastructure such as roads that contribute to sustainable development. *Environment* concerns affairs such as land management for agriculture and distant mitigation efforts. *Healthcare* expenditures include medicine and equipment and the operation of public and personal health facilities. *Housing and Public Facilities* organize the quality of residential infrastructure and water and waste services. These general accounts show that some expenditures relate more to investments in sustainable development while others are closer to current well-being.

5.3. Data and empirical strategy

5.3.1. Data source and variables

Most data for this study come from the SKID database containing subnational fiscal expenditure data provided by the Indonesian Ministry of Finance (2021). Oil and gas production facilities are located using the ESDM database by the Indonesian Ministry of Energy and Mineral Resources (2021). Data are generally complete, however, I use multiple imputation to deal with most missing values. Subsequently, regency mean values replace single remaining missing values. The final sample comprises 2680 observations for 268 non-oil and gas-producing regencies from 2008 until 2017. Table A2 in the Appendix 5A provides variable descriptions.

5.3.1.1. Dependent variables

The first dependent variable is public spending on education, which I operationalize by taking the natural logarithm of the per capita value (see Figure A1, Appendix 5A). Education is the largest public service expenditure by some margin and emerges as the main driver of sustainable development in this dissertation's previous chapters. Hence, I study this expenditure function in the most detail. Appendix 5C focuses on health expenditures per capita for similar reasons: it contributes to human capital and the second-largest expenditure function of regency governments.

Then, the analyses from Section 5.5 consider all other expenditure categories as defined by Law 13/2006. The remaining categories are economy, order and security, environment, tourism and culture, public service, social protection, and housing and public facilities. Among these functions, I identify government investments in sustainable development (education, healthcare, environment, and housing and public facilities) by checking whether the sub-categories of each function mostly entail investments that contribute to human, produced, or natural capital accumulation. The remaining categories I consider government consumption because they contribute more to meeting present-day needs.

5.3.1.2. Independent variables

The main independent variable is the natural logarithm of per capita oil and gas tax revenues (DBH Sumber Daya Alam). The log-log regression form implies that the analyses present point-elasticities, which measure the absolute effect of oil and gas windfalls on education spending.[4] Contrasting other natural resources (mining, forestry, and fishery), oil and gas production is concentrated in about a quarter of regencies, meaning a large group of non-producing regencies shares in oil and gas tax revenues. Further, oil and gas tax revenues per capita are considerably higher than other natural resource revenues and thus fund a larger share of regency government budgets. The oil and gas revenue data are also more reliable than forestry and mining data for causal identification, as spatial variation of illegal mining and deforestation activities can lead to biased estimates. The oil and gas tax revenues per capita data are approximately normally distributed (Figure A2, Appendix 5A).

5.3.1.3. Control variables

I control for various confounding factors categorized as fiscal controls and political controls. The fiscal controls are the other sources of government revenue: central government funds (DAU), special allocation funds (DAK), and

4. This approach comes with one drawback. Ideally, one would compare effect sizes between independent variables. However, point-elasticities can only be evaluated at the margin. Ceteris paribus, a large revenue source (i.e., DAU income) has a higher point-elasticity than a smaller one. Coefficients only become directly comparable when revenue sources are of near-equal size.

local taxation and other natural resources (DBH). Among the political controls is a dummy variable for local elections for regency heads (*Dupati Elections*). Balboni et al. (2021) show that governments' fiscal policy can be less wasteful during an election year to maximize votes. Local elections are asynchronous and therefore not colinear with the time-fixed effects.

Furthermore, I control for regency proliferation: the number of regencies rose sharply from 336 to over 500 during the sample period. Regency-splitting is not without controversy. Although Lewis (2017) finds that proliferation in Indonesia has not harmed school enrollment rates, there are fiscal incentives for splitting. Fitrani et al. (2005) and Pierskalla (2016) argue that it creates patronage opportunities. Hence, I include dummy variables for both host- and offshoot regencies. Although other controls such as geography (e.g., land area, precipitation, landlocked) and demographics (e.g., ethnic fractionalization, dependency ratio) likely matter for education spending, these time-invariant regency properties are colinear with the regency-fixed effects. Table 5.2 below provides summary statistics of the complete sample.

Table 5.2. Descriptive statistics of the complete sample

Variable	Mean	Std. dev	Min.	Max.	Observations
Dependent variable					
Education spending (ln per capita)	13.2	1.24	4.04	17.0	4862
Fiscal natural resource revenues					
Oil and gas (ln per capita)	6.09	5.05	0	17.3	4602
Mining (ln per capita)	7.60	3.83	0	16.4	4870
Fishery (ln per capita)	2.45	3.13	0	13.4	4870
Forestry (ln per capita)	6.55	2.64	0	14.6	4870
Fiscal controls					
DAK income (ln per capita)	12.3	1.30	4.89	16.4	4869
DAU income (ln per capita)	14.3	0.873	6.08	17.5	4879
Local tax income (ln per capita)	12.1	0.938	4.10	15.7	4896
Political controls					
Offshoot (0/1)	0.124	0.330	0	1.000	5030
Host (0/1)	0.099	0.299	0	1.000	5030
Election year (0/1)	0.070	0.254	0	1.000	5030

Notes: The statistics in this table refer to the full sample without dropping regencies with incomplete data. Variable descriptions are in Table A2. For a detailed overview of the summary statistics by regency group, see Table A3.

5.3.2. Empirical strategy

5.3.2.1. Identification

The main objective is to identify the effect of oil and gas tax revenues on public service spending. There are three types of regencies under the revenue-sharing scheme, illustrated in Figure 5.1.

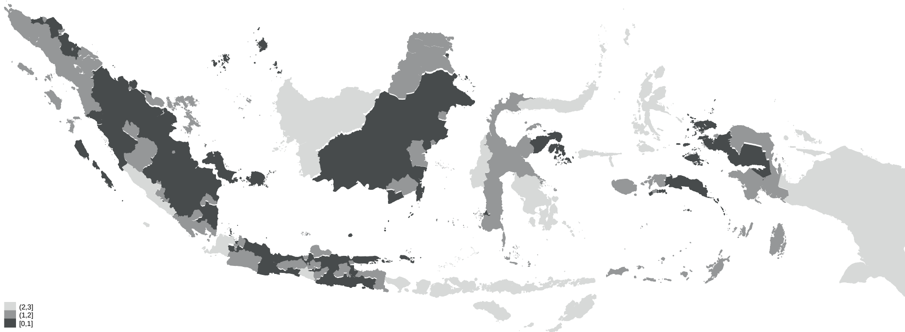


Figure 5.1. Map of oil and gas-producing, revenue receiving, and control regencies

Notes: Map indicates regency types. Darkest grey corresponds to oil and gas-producing regencies, medium grey to non-producing regencies that receive oil and gas income (treatment group), and the lightest grey indicates the control regencies. Offshore exploitation is assigned to the nearest regency. Regency identification is done using data from the Indonesian Ministry of Energy and Mineral Resources (2021).

Using the ESDM database, I first identify the oil and gas-producing regencies. The ESDM database indicates the presence of active oil and gas fields and facilities as well as their operation time. Any regency that extracts oil or gas at any time during the sample period is a producing regency. Accordingly, we ensure that the group of non-producing regencies never faces incentives to manipulate their oil and gas tax revenues. Non-producing regencies are all other regencies that never produced oil or gas but share in the tax revenues generated in the province.[5] The main control group contains regencies in non-producing provinces that collect no oil and gas tax revenues. Figure 5.2 illustrates the average the budget compositions among regency types. Appendix 5A (Table A3) presents the full summary statistics by regency type.

5. Producing provinces are Java Timur, Java Tengah, Java Barat, Jambi, Kalimantan Utara, Kalimantan Timur, Kalimantan Selatan, Maluku, Lampung, Nanggroe Aceh Darussalam, Papua Barat, Riau, Riau Kepulauan, Sumatera Utara, Sumatera Selatan, Sulawesi Tengah, and Sulawesi Selatan. See Figure 5.1.

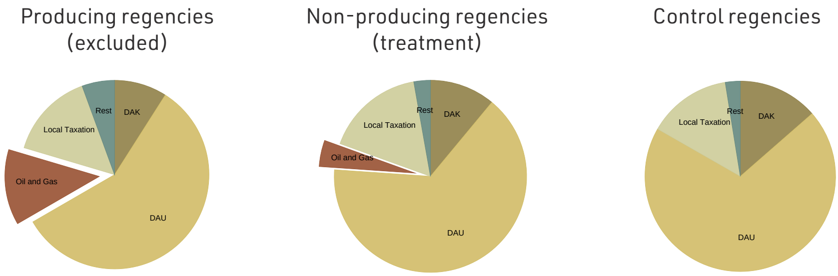


Figure 5.2. Regency government income shares

Notes: Each pie presents the sum of income from DAU, DAK, local taxation, oil and gas, and the remaining natural resources (labeled 'Rest') for each group of regencies.

I exploit exogenous variation in the independent variable, oil and gas tax revenue, by drawing on the non-producing regencies in producing provinces. These local governments cannot control oil and gas tax revenues by adjusting production volumes because those revenues are produced outside their jurisdictions. By law, the property rights to negotiate and execute contracts for exploitation are in the hands of the producing-regency local governments. Furthermore, the 6.2% and 12.2% sharing rates of oil and gas taxation, respectively, are constant and set by the laws discussed previously. This revenue allocation scheme has not undergone significant changes during the sample period. Finally, regencies that do not produce oil and gas cannot manipulate (global) oil and gas prices. Therefore, the temporal fluctuations in oil and gas revenues for non-producing regencies are plausibly exogenous.

A possible threat to the identification strategy is that oil and gas revenues could correlate with unobservables that affect budgetary decision-making. I perform the analysis with regency-fixed effects, which control for all unobserved time-invariant confounders. Also, including time-fixed effects controls for unobserved factors that non-linearly impact budget decisions over time. The set of political, fiscal, and other control variables discussed previously minimizes the omitted variable bias. Using Oster's (2019) method as a sensitivity analysis, I find that omitted variable bias is extremely unlikely to explain away the baseline results.

Furthermore, I extensively test the robustness of my results in Appendix 5D. Both types of non-producing regencies, those that collect oil and gas tax revenues and those that do not, often belong to neighboring provinces. Accordingly, a clear geographical boundary separates units that would otherwise be highly homogenous in unobserved characteristics. I exploit this geographical boundary in two ways. First, I use a sharp geographical regression discontinuity analysis to assess whether the dependent variable jumps at the border. I construct a sample of highly similar non-producing regencies using propensity score matching to perform the analysis. Second, I consider whether regencies within a pre-defined arbitrary proximity to the border benefit from being on the border's producing province side. Although the border may introduce potential compound effects, the alternative method produces very similar results as the main identification method.

5.3.2.2. Model specification

I estimate the effect of oil and gas revenues on education expenditures using regency- and time-fixed effects, clustering robust standard errors at the regency level. Equation 5.1 describes the baseline estimation:

$$E_{it} = \beta_1 R_{it} + X_{it} + \delta_i + T_t + u_{it} \qquad \text{(Eq. 5.1)}$$

where E_{it} denotes the education expenditures and subscripts of regency *i* at time *t*. R_{it} is the natural logarithm of oil and gas tax revenue per capita. X_{it}, denotes the vector of fiscal and political control variables, time fixed-effects are T_t, δ_i shows the regency-level fixed effect, and u_{it} is the error term.

The next section proceeds with the baseline results and expansions for education: the largest expenditure function and arguably the main driver of sustainable development. Appendix 5C replicates the analysis healthcare expenditures, the second-largest category. Section 5.5 discusses the other expenditure functions.

5.4. Results for public education spending

5.4.1. Baseline results

Table 5.3. Point-elasticity estimates of oil and gas tax revenues on education expenditures

Dependent variable: natural log local government education spending per capita				
	(1)	**(2)**	**(3)**	**(4)**
Fiscal revenue natural resources				
Oil and gas	0.094 (0.022) [p=0.000]	0.101 (0.022) [p=0.000]	0.095 (0.022) [p=0.000]	0.096 (0.022) [p=0.000]
Mining		-0.018 (0.012) [p=0.126]	-0.023 (0.012) [p=0.047]	-0.024 (0.012) [p=0.045]
Fishery		-0.031 (0.017) [p=0.066]	-0.033 (0.017) [p=0.050]	-0.033 (0.017) [p=0.049]
Forestry		0.025 (0.010) [p=0.008]	0.021 (0.009) [p=0.028]	0.021 (0.010) [p=0.030]
Fiscal control variables				
Central DAK revenue			0.107 (0.035) [p=0.003]	0.113 (0.036) [p=0.002]
Central DAU revenue			0.008 (0.063) [p=0.894]	0.007 (0.063) [p=0.917]
Local tax revenue			0.110 (0.054) [p=0.043]	0.120 (0.054) [p=0.028]
Political control variables				
Offshoot regency (0/1)				-0.770 (0.052) [p=0.000]
Host regency (0/1)				-0.428 (0.198) [p=0.032]
Election year (0/1)				0.112 (0.062) [p=0.069]
Time fixed effects	Y	Y	Y	Y
Regency fixed effects	Y	Y	Y	Y
Observations	3339	3257	3257	3257
# regencies	355	355	355	355
Avg. years per unit	9.4	9.2	9.2	9.2
R^2 within	0.401	0.410	0.415	0.416

Notes: The table presents fixed-effect model estimates. The sample includes only non-oil and gas-producing regencies, so oil and gas revenue is exogenous. Coefficients indicate point-elasticities. Standard errors in parentheses are clustered at the regency level. (0/1) indicates a dummy variable.

Table 5.3 presents the baseline results for the complete sample using a fixed-effects model with standard errors clustered at the regency level. The analysis does not account for spatial autocorrelation.[6] The columns add control variables iteratively for gauging the coefficient stability. Results show that a 1% local oil and gas tax revenue increase leads to 0.066% more per capita education spending. The positive effect remains within the 99.9% confidence interval for all estimations of the model. The elasticity may seem low; however, oil and gas' contribution to regency budgets is small, while education is the largest expenditure. An elasticity of 0.1 implies that approximately 36% of additional resource revenues is spent on education at the margin.[7] The ratio of oil and gas revenue to education for the average regency is 22.5%, meaning that oil and gas tax windfalls are spent more than proportionally on education. Oil and gas tax revenues and other independent variables jointly account for significant within-regency variation in education expenditures, explaining 51% of the total variation ($\rho = 0.49$).

These results strongly suggest that local governments do not squander oil and gas windfalls; conversely, they spend them more on education than other revenue sources. The point-elasticity estimates among significant budget variables are remarkably similar, even though DAK revenue and local taxation constitute a larger share of the revenue ledger. In other words, governments spend additional oil and gas revenues more on education than an equivalent increase in local taxation or earmarked funds (DAK). These findings challenge the conventional wisdom that natural resource revenues are squandered (Brollo et al. 2013; Paler 2013) because they are spent less on public services than local taxes (Gadenne 2017).

Appendix 5B presents extensive sensitivity analyses. The coefficients prove stable across various sampling methods, minimizing the risk of sampling bias. Similarly, the oil and gas windfalls' coefficient is robust to omitted variable bias as evaluated using Oster's (2019) method.

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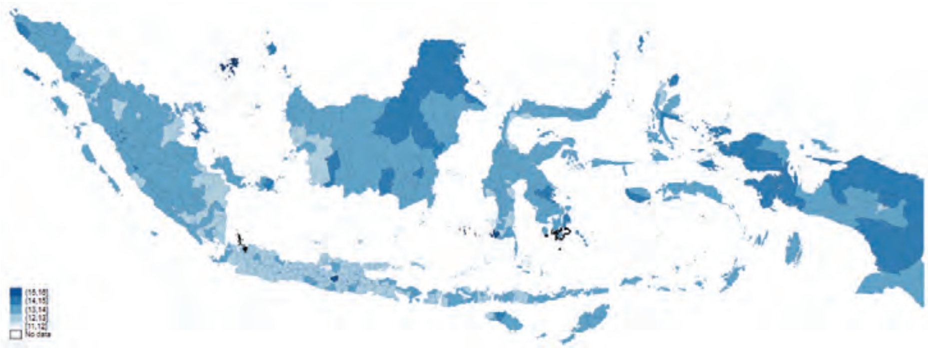
6. As discussed previously, the strongly balanced panel restriction requires omitting several regencies. Table 5.3 displays results with the largest possible sample.
7. Table 5.7 in Section 5 produces this number and compares it to the other expenditure functions.

5.4.2. Inter-regency political competition and spatial spillovers

5.4.2.1. Methods

Although the baseline analyses are generally complete, the next step is to account for the spatial clustering of spending habits. Local governments do not operate in a vacuum; instead, at the subnational scale, local governments' performances is measured against their neighbors' (Besley and Case 1995). This "yardstick effect" predicts spatial clusters of education spending; local politicians are incentivized to follow suit if neighboring regions invest more in education. Similarly, some provinces have more oil and gas fields than others, leading to spatial clustering of oil and gas revenues. Figure 5.3 below present the relevant maps.

Education



Oil and gas

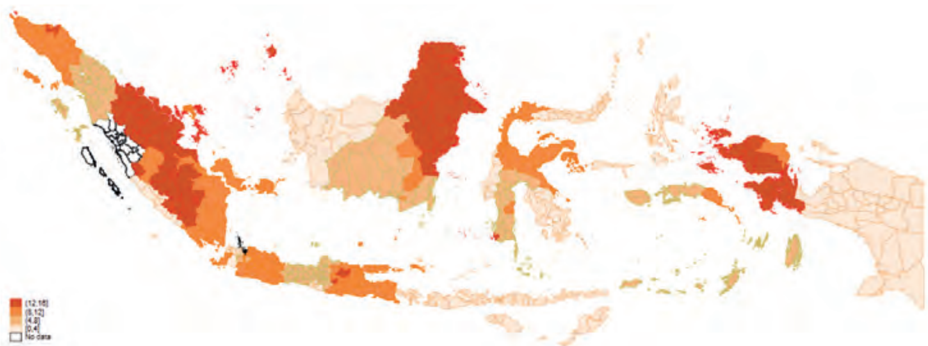


Figure 5.3. Mean education spending and oil and gas revenue per capita by regency

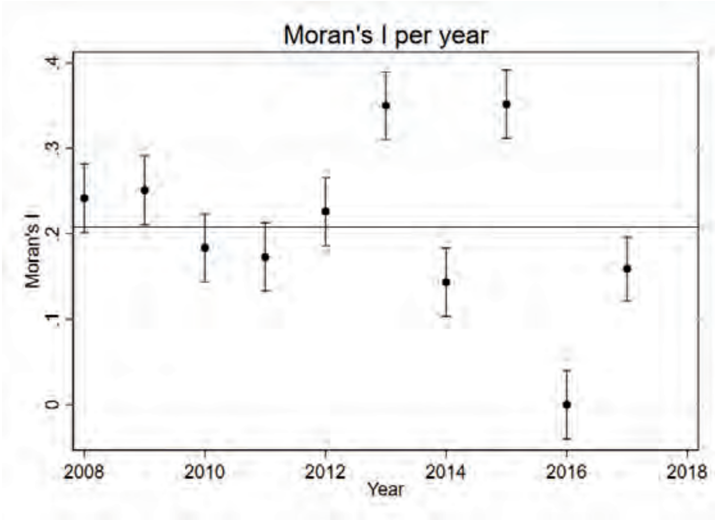


Figure 5.4. Moran's I for education throughout the sample period

The maps suggest that education spending, the dependent variable is spatially correlated, confirmed by parameter Moran's I (Figure 5.4).[8] Spatial autocorrelation can be explained by similarities between regencies, which I capture in the independent variables and the fixed effects, or by the yardstick argument. To include the latter, I expand the analysis to account for spatial autocorrelation. I follow Lee and Yu's (2010) approach of a spatial autoregressive panel model with two-way fixed effects, described by Equation 5.2 below:

$$E_{it} = a_i + (\theta W)R_{it}\beta + \lambda W E_{it} + X_{it} + T_t + u_{it} \quad i = 1, \ldots, n$$

$$u_{it} = (\rho M u_{it}) + \varepsilon_{it} \qquad \text{(Eq. 5.2)}$$

where E is education spending per capita and R is oil and gas tax revenue per capita for regency i at time t. X_{it} is a vector of time-varying control variables, and T_t is the year fixed-effects. W and M are spatial weighting matrices calculated as inverse distances among all regencies. λ indicates the spatial lag of the dependent variable E. Some model specifications include a spatial lag for the independent variable R with parameter θ. Finally, a spatial lag of the error term ρ is present in others.

8. Notably, the figure suggests no spatial autocorrelation in the year 2016. Removing that year from the sample does not change coefficients meaningfully. Isolating that year finds similar results.

The spatial autocorrelation fixed-effects model requires a perfectly balanced sample without missing observations. The approach omits all regencies with at least one missing observation for any of the included variables in the baseline effects model. As a result, the sample shrinks to 2680 observations with 268 regencies, each having ten observations between 2008-2017.

5.4.2.2. Results

Table 5.4 presents the results. Oil and gas revenues' coefficient remains positive and comparable to the baseline model. The spatial autocorrelation component also has a positive and significant effect, providing evidence for the yardstick performance phenomenon. Regencies spend more on education as neighboring regencies increase their spending. Local competition in education spending emerges because small geographical units allow citizens to attend schools in other regencies. The effect is strong. Ceteris paribus, a regency spends about 0.4% more on education when the average neighboring regency spends 1% more on education.

Turning to the main results, column 2 of Table 5.4 shows that fluctuations in oil and gas revenues in geographically proximate regencies do not explain education spending outcomes. Hence, while there is significant spatial correlation in the independent variable, it is irrelevant for understanding how oil and gas windfalls are spent on education. More interestingly, the error term is spatially correlated, meaning that the fit of the general model is higher for some areas than others. When correcting for this, the results become more robust but less precise. Nevertheless, the causal effect of oil and gas tax revenues on education spending remains unshaken. The coefficient is stable, meaning that even when accounting of spatial clustering, governments spend these resource revenues disproportionally on education.

Table 5.4. Spatial autoregressive fixed effects models

	Spatial lag model (1)	Spatial lag model (2)	Spatial Durbin model
	Main effects		
Fiscal revenue natural resources			
Oil and gas	0.088 (0.032) [p=0.006]	0.115 (0.043) [p=0.007]	0.079 (0.031) [p=0.011]
Mining	-0.015 (0.013) [p=0.249]	-0.017 (0.013) [p=0.185]	-0.017 (0.012) [p=0.175]
Forestry	0.015 (0.010) [p=0.141]	0.016 (0.010) [p=0.129]	0.013 (0.010) [p=0.169]
Fishery	-0.031 (0.017) [p=0.066]	-0.030 (0.017) [p=0.067]	-0.034 (0.016) [p=0.036]
Fiscal control variables			
Central DAK revenue	0.097 (0.034) [p=0.005]	0.097 (0.034) [p=0.005]	0.088 (0.034) [p=0.009]
Central DAU revenue	-0.064 (0.051) [p=0.210]	-0.066 (0.051) [p=0.200]	-0.060 (0.051) [p=0.244]
Local taxation revenue	0.052 (0.052) [p=0.317]	0.052 (0.052) [p=0.310]	0.050 (0.051) [p=0.331]
Political control variables			
Host regency (0/1)	-0.379 (0.206) [p=0.066]	-0.382 (0.206) [p=0.064]	-0.362 (0.206) [p=0.078]
Offshoot regency (0/1)	-0.729 (0.531) [p=0.169]	-0.688 (0.532) [p=0.196]	-0.796 (0.531) [p=0.134]
Year fixed effects	Yes	Yes	Yes
Regency fixed effects	Yes	Yes	Yes
	Spatial autoregressive coefficient		
Education	0.385 (0.052) [p=0.000]	0.398 (0.053) [p=0.000]	0.444 (0.051) [p=0.000]
Oil and gas		-0.110 (0.112) [p=0.328]	
Error term			-0.251 (0.109) [p=0.022]
Observations	2680	2680	2680
# regencies	268	268	268
Avg. years	10	10	10
AIC	6023.861	6024.903	6020.870
BIC	6141.732	6148.668	6144.635

Notes: The table presents the spatial fixed effects estimates for the sample of non-oil and gas-producing regencies without missing observations between 2008 and 2017. All models include a spatial lag of the dependent variable. The second model adds a spatial lag of the independent variable. The third model includes a spatial lag of the error term. Standard errors are in parentheses.

5

5.4.3. Digging deeper: Accounting for tax substitution effects

The final analysis digs deeper into the causal chain and looks for a mechanism to explain how oil and gas revenues increase education spending. We assess whether regency governments that receive oil and gas tax windfalls lower local taxation, leading to a local substitution effect. The rationale is that government can use the additional fiscal capacity to decrease local taxation for political gains. Similarly, I assess whether oil and gas windfalls lower funds from the central government (DAU), leading to a central substitution effect. I estimate a structural equation model (SEM) to assess the local and central substitution effect on education simultaneously. Figure 5.5 illustrates the model, described by three simple equations:

$$E_{it} = a_i + \beta_1 R_{it} + \tilde{X} + \beta_2 L_{it} + \beta_3 DAU_{it} T_t + u_{it} \qquad \text{(Eq. 5.3)}$$

$$L_{it} = a + \beta_3 R_{it} + \beta_4 DAK + \beta_5 Resources + \varepsilon_{it} \qquad \text{(Eq. 5.4)}$$

$$DAU_{it} = a + \beta_6 R_{it} + \beta_7 DAK + \beta_8 Resources + \varepsilon_{it} \qquad \text{(Eq. 5.5)}$$

where Equation 5.3 is identical to baseline Equation 5.1. However, the vector for control variables $\tilde{X}$ does not contain endogenous variable L for local taxation. Equation 5.4 shows that local taxation per capita is a function of all other budgetary incomes. I assume that local politicians adjust local taxes to the size of other revenue streams. Similarly, I conjecture that the central Indonesian government may (ab)use the opacity of DAU calculations to tamper with the size of central grants (Equation 5.5).

Table 5.5 presents the results. The first column displays the direct effects of the independent variables on education spending per capita. The second and third columns show the effects of the budget components on local taxation and DAU, respectively, which in turn affect education spending. Oil and gas revenues still positively affect education spending, although the elasticity is lower than in the baseline estimations. The direct effect dominates the total effect. Opposite to a local substitution effect, I find that oil and gas tax windfalls increases local taxation. This, in turn, further increases education spending. Similarly, oil and gas income does not crowd out central government grants.

I propose two explanations for the complementarity of local taxation and oil and gas windfalls. First, the oil and gas variable may approximate backward linkages in the extraction sector. Oil and gas production generates additional income for downstream suppliers, which may be located in non-producing regencies of a province. Hence, extra-regency oil and gas production may increase local tax income in a non-producing regency. Second, citizens' willingness to pay taxes may be higher when governments spend oil and gas income productively, as the analysis shows they do. The government's productive use of tax revenues, especially compared to the pre-decentralization autocratic rule period, can bolster citizens' favorable disposition towards local leader and discourage citizens from tax avoidance.

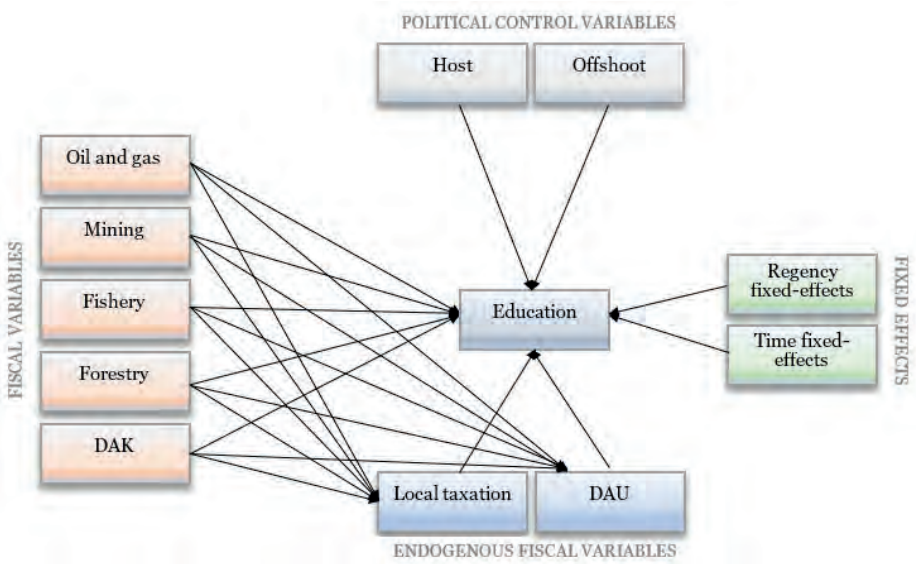


Figure 5.5. Structural equation model

Table 5.5. Structural Equation Model (SEM): Mediation analysis

	Dependent variable: ln government education spending per capita			
	Endogenous variable effects			
	(1) Direct effect	**(2) Indirect effect: Local tax income**	**(3) Indirect effect: DAU**	**(4) Total Effect**
Fiscal revenue natural resources				
Oil and gas	0.043 (0.018) [p=0.018]	0.046 (0.004) [p=0.000]	-0.002 (0.002) [p=0.316]	0.046
Mining	0.003 (0.010) [p=0.752]	0.023 (0.005) [p=0.000]	0.024 (0.004) [p=0.000]	0.012
Fishery	-0.047 (0.017) [p=0.006]	-0.041 (0.006) [p=0.000]	0.048 (0.004) [p=0.000]	-0.035
Forestry	0.017 (0.009) [p=0.058]	-0.021 (0.006) [p=0.000]	-0.017 (0.003) [p=0.000]	0.012
Fiscal control variables				
Central DAK revenue	0.115 (0.030) [p=0.000]	-0.094 (0.020) [p=0.000]	-0.428 (0.014) [p=0.000]	-0.024
Central DAU revenue (endogenous)	0.310 (0.089) [p=0.001]			0.310 (0.089) [p=0.001]
Local tax revenue (endogenous)	0.070 (0.048) [p=0.145]			0.070 (0.048) [p=0.145]
Political control variables				
Offshoot regency (0/1)	-0.278 (0.220) [p=0.207]			-0.278 (0.220) [p=0.207]
Host regency (0/1)	-0.338 (0.162) [p=0.037]			-0.338 (0.162) [p=0.037]
Time fixed effects		Y		
Regency fixed effects		Y		
Observations		2784		
# regencies		355		

Notes: The table presents the generalized structural equation model corresponding to Figure 5.5. The sample considered includes only non-oil and gas producing regencies so that oil and gas revenue is exogenous. The first column indicates the direct effect of the independent variables on education spending. The second and third column indicate the estimation where local taxation and DAU are the dependent variable, respectively. The third column combines all into its total effects. Standard errors in parentheses are clustered at the regency level. (0/1) indicates a dummy variable.

Although I find no evidence of oil and gas revenues lowering central government transfers (DAU), there is evidence of central tax substitution from a different source. The SEM results find that DAK revenues, often earmarked for education, have a net negative effect on education spending. Regencies that receive more DAK revenues collect less local taxation and receive less central funds (DAU). Hence, even though the central government gives special priority to education expenditures in some regions, the appropriate funds (DAK) effectively cancel out other revenue streams. The local government is forced to reallocate funds without enjoying an expanded capacity to provide public education services.

5.5. Results for all expenditure functions

This section studies the effect of exogenous oil and gas tax windfalls on all other government expenditures. Table 5.6 presents a complete overview using all other expenditure functions as dependent variables. The estimated models are akin to those that underlie Table 5.3 and Table C1 from Appendix 5C, using education and healthcare spending as dependent variables, respectively. The models include the standard control variables (fiscal and political) and time- and regency-fixed effects. Each column displays an expenditure function as a dependent variable, also reporting the variable's sample mean for that spending category.[9] In addition to the expenditure functions, the table presents aggregated expenditure functions into government consumption versus sustainable investments.

The analysis shows that oil and gas tax windfalls positively affect most government expenditures. Unsurprisingly, this indicates that governments do not spend less on certain functions as their budgets expand. The variations among coefficients is more interesting. Evidently, education has the largest coefficient, indicating that windfalls are primarily used to fund education. No statistically significant positive effect appears for order and security, tourism and culture, and public services. These spending categories fall under government consumption and do not involve investments in human, produced, or natural capital assets. Although the model's explanatory power is low, it appears that local taxes play a more significant role in financing tourism and culture, which is a customary practice.

9. Recall that the larger the mean value of the dependent variable, the smaller the expected coefficient becomes, ceteris paribus.

To understand the differences in coefficients among the expenditure functions better, I calculate the marginal propensity of oil and gas tax windfalls for each expenditure category in Table 5.7. In other words, I examine how an additional unit of oil and gas tax revenue is allocated to a category. I relate this to its current share in the budget to show how spending priorities differ between the margin and the average. The difference indicates whether governments spend natural resource windfalls proportionally or disproportionately for each spending category. Among the significant expenditure functions, four categories of spending emerge as priorities, in descending order: environment (17 percentage point difference), social protection (15 percentage points), healthcare (12 percentage points), and education (8 percentage points).

Three of these four categories are associated with sustainable development investments. Expenditures on the environment entail investing in and preserving nature and ecosystems, meaning its expenditures contribute to the (net) accumulation and preservation of natural capital. Healthcare and education are the main components of human capital. Social protection is the only category associated with current well-being. Hence, the findings suggest that local rulers prioritize spending windfalls on public services that contribute to sustainable development. The coefficients for the aggregate spending categories (i.e., sustainable investments and government consumption) in Models 16 and 17 in Table 5.6 support these findings.

The increase in funding allocated to the environment is noteworthy, as this category comprises only 1.5% of the budget but receives 18.2% of windfall funds. Since oil and gas tax revenues are not earned locally, this cannot be attributed to NIMBY sentiments. A possible explanation that requires further study could be that environmental protection may be a secondary priority because provinces are primarily responsible. Local leaders may be hesitant to use taxes and general funds for the environment but may be more willing to contribute when additional funds become available. Alternatively, when oil and gas windfalls turn out to be lower than expected, the local budget for environmental protection is slashed hardest.

Similarly, increased social protection spending (from 1.8% to 16.5%) may reflect a willingness to supplement national-level social safety nets only when budgets allow it. However, since social protection includes transfers to citizens, the sharp increase in spending may reflect a crude attempt to gain political support. I revisit this argument in the following section.

Table 5.6. The effect of oil and gas windfalls on all remaining expenditure functions

	Separate expenditure functions							Aggregated	
	(9)	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**	**(16)**	**(17)**
Dependent variable	Economy	Environment	Order & Security	Tourism & Culture	Public Services	Social Protection	Housing and Public Facilities	Sustainable Investment	Public Consumption
Dep var μ	12.330	10.599	10.405	9.683	13.503	10.653	12.681	14.129	13.950
Oil and gas	0.042 (0.020) [p=0.041]	0.061 (0.023) [p=0.008]	0.029 (0.018) [p=0.121]	0.020 (0.029) [p=0.489]	0.034 (0.018) [p=0.053]	0.055 (0.019) [p=0.005]	0.059 (0.020) [p=0.004]	0.058 (0.014) [p=0.000]	0.038 (0.018) [p=0.031]
Mining	0.040 (0.010) [p=0.000]	0.009 (0.013) [p=0.484]	0.026 (0.011) [p=0.024]	0.040 (0.019) [p=0.033]	0.025 (0.011) [p=0.021]	0.028 (0.010) [p=0.007]	-0.005 (0.010) [p=0.611]	0.006 (0.008) [p=0.437]	0.018 (0.009) [p=0.042]
Fishery	-0.018 (0.011) [p=0.115]	-0.023 (0.015) [p=0.139]	-0.015 (0.015) [p=0.312]	0.004 (0.016) [p=0.825]	-0.005 (0.012) [p=0.711]	-0.009 (0.015) [p=0.519]	0.020 (0.016) [p=0.218]	0.001 (0.009) [p=0.954]	-0.004 (0.010) [p=0.650]
Forestry	0.007 (0.007) [p=0.353]	0.006 (0.010) [p=0.563]	-0.010 (0.008) [p=0.246]	0.025 (0.013) [p=0.061]	0.027 (0.010) [p=0.006]	0.004 (0.009) [p=0.615]	0.008 (0.008) [p=0.310]	0.013 (0.005) [p=0.014]	0.018 (0.006) [p=0.003]
DAK	0.049 (0.027) [p=0.074]	0.112 (0.032) [p=0.001]	0.075 (0.038) [p=0.050]	-0.033 (0.046) [p=0.477]	0.019 (0.027) [p=0.482]	0.127 (0.029) [p=0.000]	0.038 (0.032) [p=0.243]	0.098 (0.026) [p=0.000]	0.019 (0.020) [p=0.345]
DAU	0.065 (0.072) [p=0.367]	0.036 (0.047) [p=0.444]	0.127 (0.056) [p=0.025]	-0.013 (0.110) [p=0.903]	0.131 (0.080) [p=0.103]	0.071 (0.076) [p=0.349]	-0.018 (0.077) [p=0.811]	0.022 (0.035) [p=0.537]	0.084 (0.049) [p=0.091]
Local taxation	0.127 (0.044) [p=0.004]	0.135 (0.050) [p=0.008]	0.078 (0.044) [p=0.076]	0.255 (0.074) [p=0.001]	0.081 (0.038) [p=0.034]	0.129 (0.047) [p=0.006]	0.144 (0.053) [p=0.007]	0.114 (0.036) [p=0.002]	0.102 (0.034) [p=0.003]
Political Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regency fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 5.6. Continued

	Separate expenditure functions							Aggregated	
	(9)	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**	**(16)**	**(17)**
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	3103	3038	3069	2679	3107	3078	3094	3016	2633
R^2 *-within*	0.229	0.123	0.232	0.158	0.282	0.247	0.405	0.562	0.297

Notes: The table presents fixed-effect model estimates. The sample includes only non-oil and gas-producing regencies, so oil and gas revenue is exogenous. Coefficients indicate point-elasticities. Standard errors in parentheses are clustered at the regency level. (0/1) indicates a dummy variable. Sustainable investments in Model 16 is the aggregation of Education, Health, Environment, and Housing and Public Facilities. Government consumption is the aggregation of all remaining expenditure functions.

Table 5.7. Marginal propensity of expenditure functions

Expenditure Function	Sample mean (natural log)	Coefficient (elasticity)	p-value	Share (current)	Propensity	Difference
Education	13.221	0.096	0.001	0.276	0.358	0.082
Healthcare	12.517	0.066	0.000	0.114	0.233	0.119
Economy	12.330	0.042	0.041	0.085	0.146	0.061
Environment	10.599	0.061	0.008	0.015	0.182	0.168
Order & Security	10.405	0.029	0.121	0.023	0.085	0.062
Tourism & Culture	9.683	0.02	0.489	0.008	0.055	0.047
Public Services	13.503	0.034	0.053	0.277	0.130	-0.148
Social Protection	10.653	0.055	0.005	0.018	0.165	0.148
Housing and Public Facilities	12.168	0.059	0.004	0.146	0.203	0.056

Notes: The table draws means, coefficients, and p-values from the full baseline regressions in Tables 5.3, B1, and 5.6. Share (current) is the percentage of total expenditures spent on that particular function. Propensity is the percentage spent on the function at the margin (i.e., percentage of one marginal rupiah spent on that function), implied by rearranging the elasticity function , where *y* is the dependent variable and *x* is oil and gas revenues. The difference between the current share and propensity is in the final column.

Approximating the likelihood of political motives interfering with budgetary decisions is challenging, as I can only observe revenues and spending patterns and not the actual political decision-making process. A priori, one might expect governments to pander more to the population by increasing consumption disproportionately following a windfall. The final analysis further explores political manipulation by considering inter-regional heterogeneity of institutional and financial regulatory quality, which may explain why some regencies spend windfalls more sustainably. I use data from the Regional Autonomy Watch KKPOD (2003). This organization compiles institutional quality scores for Indonesian regencies based on properties such as abuse of authority and quality of regional government finance. Even though other studies also utilize KKPOD data (e.g., Pelzl and Poelhekke 2021), a notable downside is that only 131 of 514 regencies are present in the sample.

The dependent variable is government sustainable investments—i.e., the aggregation of expenditures functions with produced, human, or natural capital assets. The analysis involves two samples: one with non-producing regencies and another with all regencies. Iterations of the model separately add a standardized moderating variable: institutional quality or financial regulatory quality in 2003.[10] These variables are time-invariant, so their main effects are colinear with the regency fixed effects. The interaction effect, however, reveals whether regencies with higher institutional quality or regulatory finance quality allocate windfalls more toward sustainable goals. Table 5.8 presents the results.

Across both samples, the coefficient of oil and gas revenues is stable, sizably positive, and highly statistically significant. The positive and significant interaction effect for regulatory quality indicates that regencies with higher-quality regional finance standards spend a larger share of windfalls on sustainable functions. This result is consistent with the idea that regencies with weak institutions may opt for more political pandering or hide expenditures in functions that serve immediate needs. They may abuse the opacity of budget details for pursuing self-interests. Nonetheless, only the worst 3% of regencies in financial regulatory quality will have a net negative effect. Therefore, while some degree of squandering may occur, the analysis demonstrates that oil and gas tax windfalls contribute to sustainable development across the board.

10. More recent data are not available. However, because rankings are relatively constant over time on average, I can presume that the 2003 observations are still largely applicable to later years.

Table 5.8. The moderating effect of institutions and financial regulatory quality: An interaction analysis

Dependent variable: Sustainable investments	**Non-producing regencies only**			**All regency types**		
	(18)	**(19)**	**(20)**	**(21)**	**(22)**	**(23)**
Oil and gas	0.101 (0.028) [p=0.001]	0.108 (0.030) [p=0.001]	0.103 (0.033) [p=0.002]	0.091 (0.022) [p=0.000]	0.091 (0.022) [p=0.000]	0.093 (0.026) [p=0.000]
Financial regulatory quality × Oil and gas		0.062 (0.036) [p=0.090]			0.050 (0.021) [p=0.020]	
Institutional quality × Oil and gas			-0.007 (0.023) [p=0.774]			-0.005 (0.019) [p=0.810]
Fiscal control variables	Yes	Yes	Yes	Yes	Yes	Yes
Political control variables	Yes	Yes	Yes	Yes	Yes	Yes
Regency fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Producing regencies included	No	No	No	Yes	Yes	Yes
N	775	775	775	1220	1220	1220
# regencies	84	84	84	131	131	131
R^2	0.587	0.589	0.588	0.600	0.602	0.600

Notes: The table presents fixed-effect model estimates. Coefficients indicate point-elasticities. Standard errors in parentheses are clustered at the regency level. Control variables are identical to the ones used in baseline regression (16) in Table 5.6.

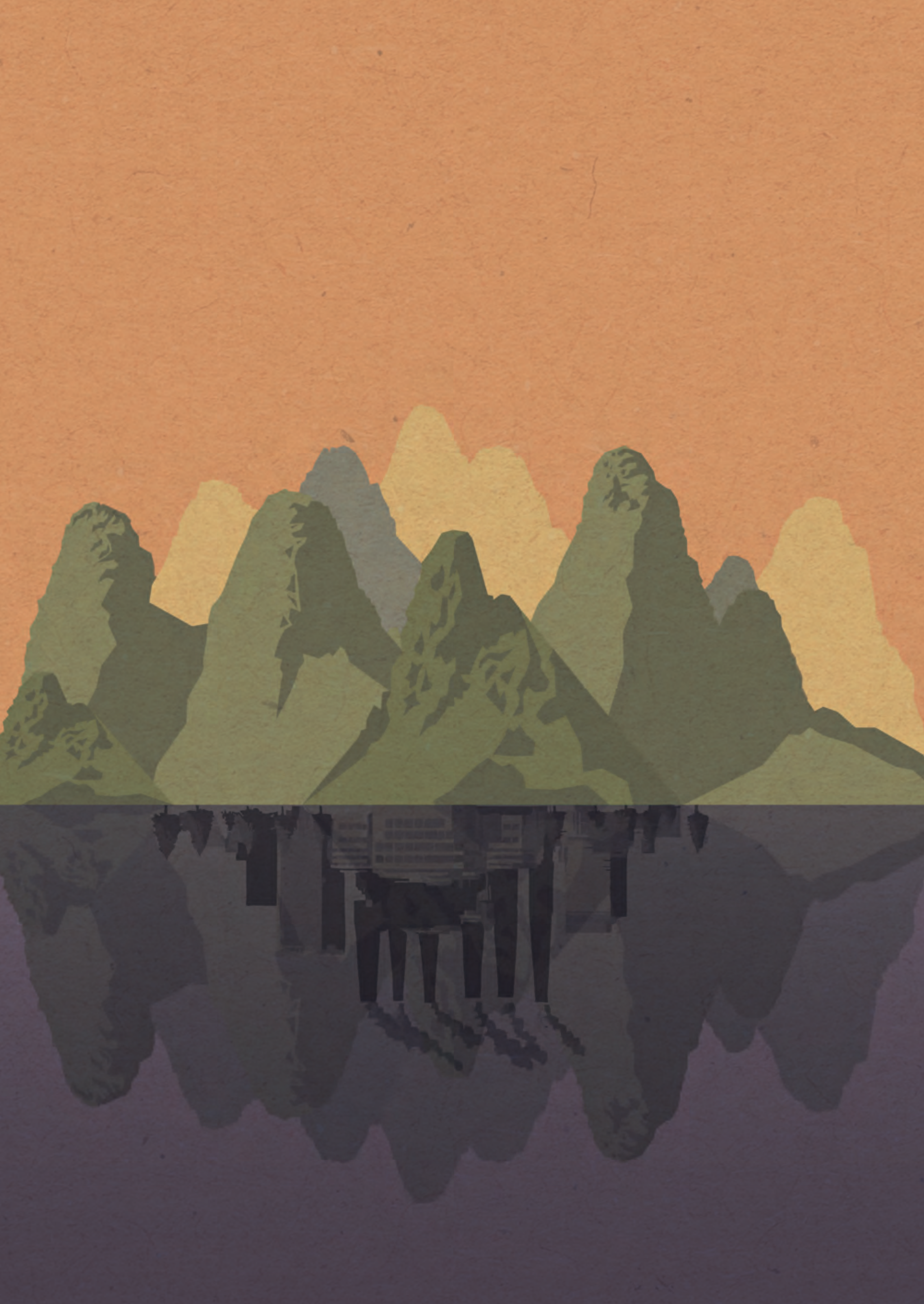
5

5.6. Conclusion

Using a case study of Indonesian regencies, this study investigates the causal effect of natural resource revenue windfalls on public service spending. I show how exogenous oil and gas revenue windfalls affect local government spending across public services. Oil and gas windfalls are spent predominantly on education, healthcare, the environment, and social protection. This finding suggests that local politicians prioritize investing windfalls on items that contribute to sustainable development. The empirical evidence also shows local Indonesian governments spend oil and gas tax windfalls more on sustainable functions than revenues from other sources, such as local taxation and central funds. This challenges the conventional wisdom that countries squander natural resource revenues. The chapter provides novel causal evidence that resource revenues can foster sustainable development via fiscal spending.

Moreover, natural resource revenues increase local tax incomes. A potential explanation is that a prospering resource sector creates a thriving local economy, resulting in higher local tax contributions, bolstering public investments in human capital. Although the positive effect of oil and gas windfalls on sustainable development spending is universal across regencies, variation in institutional quality explains some cross-regency heterogeneity.

This study raises an important question: is it better to distribute resource taxation locally than centralizing tax collection? The Indonesian example hints that a decentralized sharing mechanism may be better for sustainable development, although more research is required. The question is particularly relevant to resource-rich countries with geographically uneven distribution of natural resource endowments. Such countries may experience rising within-country inequalities in economic performance as a result of resource extraction. If a sharing arrangement can sustainably support non-resource rich regions, this could be beneficial to mineral-rich countries that are in a window of opportunity as the imminent transition towards a low-carbon world draws closer.



Chapter 6.

Conclusion

6.1. Summary

This dissertation aims to improve our understanding of how natural capital exploitation can contribute to sustainable development, delivering four empirical studies. It studies whether and how countries convert natural resources into other human, produced, and natural capital assets that are used to meet the needs of future generations. This chapter first summarizes the main findings of Chapters 2 through 5. A discussion of the implications and policy prescriptions follows. The final sections explore this dissertation's limitations and possibilities for future research.

Part I

In contrast to recent studies that prompt optimism, **Chapter 2**'s empirical analysis portrays a grim outlook on long run development for resource-rich countries. It finds that Inclusive Wealth diverges across countries. Resource-rich countries simultaneously experience a relative and absolute decline in per capita Inclusive Wealth, signaling that their improving their standards of living today will inevitably deteriorate. This trend is worrisome because Inclusive Wealth captures countries' income-earning potential. Hence, the income figures from recent studies can be deceptive. Inclusive Wealth divergence implies that present-day economic convergence is unsustainable and temporary.

Chapter 2's analysis also finds increasing returns to human capital accumulation. Human capital appears to be the most significant driver of Inclusive Wealth growth and sustainable development. Wealthier countries are more human capital abundant. Therefore, they benefit from having a better-educated population and are better able to secure a prosperous future. Conversely, poorer nations cannot capitalize on increasing returns to human capital accumulation. This puts natural resource-rich nations at a disadvantage. To achieve sustainable development, they must transition towards a more human-capital-intensive economy that can generate wealth more effectively.

Whereas Chapter 2's analysis suggests natural resource richness is a curse, **Chapter 3** shows that countries' rate of sustainable development improves when exploiting natural resources. The empirical results indicate that as countries decumulate natural capital, the rate of Inclusive Wealth growth increases. Therefore, natural resource-rich countries appear to have a disadvantage that gradually improves as they exploit natural resources. Figure 6.1 illustrates this outcome.

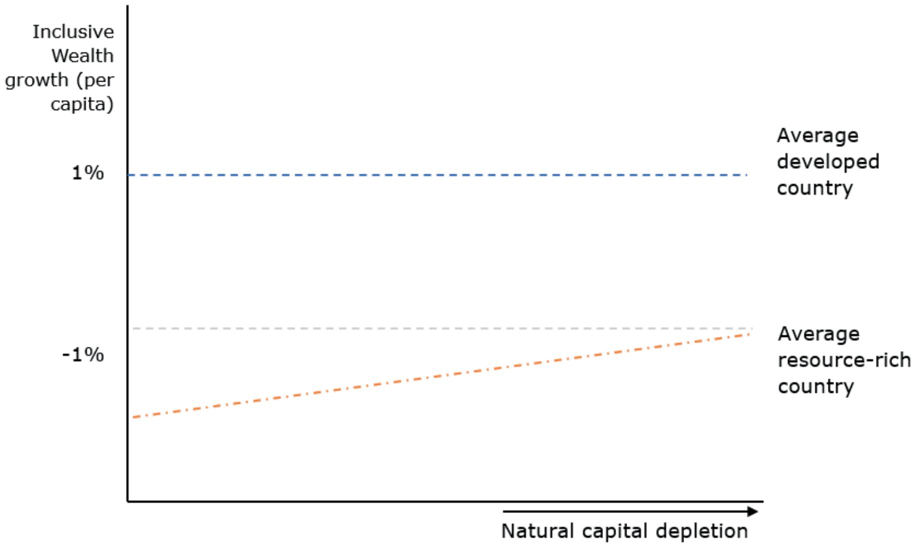


Figure 6.1. Natural capital and Inclusive Wealth growth: evidence from Part I

Notes: The figure shows how the average resource-rich country's rate of Inclusive Wealth growth increases as natural capital declines, perhaps tending toward a grey asymptote. However, this group of countries remains disadvantaged compared to the average developed country. This is the key to reconciling the results of Chapters 2 and 3. The presented growth rates are rough approximations of annual Inclusive Wealth growth across the two groups.

Although sufficient or successful natural resource conversion is consistent with the results from Chapters 2 and 3, it is not the only potential explanation. It is conceivable that human- and produced capital are more productive capital types,[1] meaning that they foster Inclusive Wealth growth more than natural capital. As natural capital depletes, countries become less reliant on natural capital and increasingly use human- and produced capital instead. Consequently, the rate of sustainable development increases (i.e., it becomes less negative) not due to resource conversion but by relying on better production factors. This explanation, however, does not necessarily mean that natural resources are converted sufficiently.

1. This requires that the monetary returns to human and produced capital are not equal to their societal returns (i.e., there are positive externalities).

Furthermore, Chapter 3 does not find a positive correlation between natural capital depletion and Inclusive Wealth growth in developed countries. Only developing and resource-rich countries show a positive relationship. The difference between developed and developing countries can be explained by differences in social returns of produced- and human capital investments. Developing countries have more investment opportunities with high socio-economic gains. Human- and produced capital accumulation requires smaller investments when such assets are scarce. In other words, when a population is uneducated and lacks infrastructure, a small investment of natural resource revenues can benefit future generations significantly. In contrast, developed countries require more sizeable investments to achieve an equal gain. Consequently, ceteris paribus, it is more challenging for developed countries to achieve Inclusive Wealth growth by depleting natural capital than it is for developing countries.

By extension, although the marginal benefits of natural resource depletion are initially high in resource-rich and developing countries, the potential gains become smaller as human- and produced capital accumulate. These countries will increasingly struggle to convert natural capital into more useful capital assets. Accordingly, the prospective benefits of resource exploitation decrease as more natural capital is converted. Natural resource exploitation is, at best, only a temporary strategy for development.

Thus, there is no conclusive evidence on whether countries are successful in converting natural capital to achieve sustainable development. Nevertheless, the findings from Chapters 2 and 3 are consistent with the idea that resource-rich countries fail to convert natural resources to achieve sustainable development. These countries have lower rates of sustainable development, which increase slowly as fewer natural resources remain. Furthermore, Chapter 2 finds GDP convergence in the short-run and Inclusive Wealth divergence in the long-run, which is suggestive evidence of a lack of natural resource conversion. Exploiting natural resources increases GDP disproportionally, resulting in convergence in the short-run, but comes at the expense of Inclusive Wealth, resulting in divergence in the long-run. The juxtaposition, therefore, has the properties of insufficient natural resource conversion, even though alternative explanations exist.

Part II

Part II of this dissertation examines the process of natural resource conversion, which comprises four stages:

1. First, natural resource deposits are prospected and discovered.
2. Second, contracts for extraction and production are negotiated and executed.
3. Third, a strategy to appropriate the resulting natural resource rents is continuously adapted to changing circumstances.
4. Finally, the government taxes natural resource revenues and reinvests some proceeds to accumulate inclusive wealth.

Chapter 4 studies the effect of four variables that correspond with the four stages on sustainable development. Accordingly, it approximates how the stages determine the conversion of natural resources. Initial evidence suggests that government spending in the final phase contributes to sustainable development. The chapter provides further causal evidence in a cross-country setting for oil, gas, and coal exploitation. It finds that most countries experience a decrease in sustainable development during the extraction and export phase. Although extraction increases sustainable development, the loss of value from exports exceeds the benefits of extraction for the average country. Countries with good quality institutions are able to develop sustainably by extracting and exporting the aforementioned resources. Additionally, countries that rely heavily on these energy exports can escape the resource curse. A potential explanation is that these countries are able to leverage their comparative advantage in the energy sector. One key finding, therefore, is that resource exports can both foster and inhibit sustainable development via the natural resource conversion process.

Chapter 5 further examines the final stage of the resource conversion process: the trade-off between government consumption and reinvestments. Specifically, the chapter studies the causal effect of natural resource tax revenues on fiscal spending using a case study of Indonesian local governments. Exploiting plausibly exogenous variation in local governments' oil and gas revenues, the chapter's analysis reveals a tendency of local politicians to spend resource windfalls on education, healthcare, and the environment. These expenditure functions are associated with human capital (education, health) and natural capital (the environment) accumulation. Therefore, the study shows that local politicians allocate a sizeable share of resources to sustainable development. Provided that they also spend significantly on social protection, this implies that politicians balance the needs of present and future generations. Together, Chapters 4 and 5 provides compelling evidence supporting that government spending promotes sustainable development.

6.2 Implications and policy relevance

6.2.1 Resource exploitation is no panacea

An implication for policy is that natural resource exploitation for sustainable development is not one-size-fits-all. Developed economies convert natural capital less effectively for two reasons. First, they lack a comparative advantage in the resource sector which increases the gains from resource exploitation (Chapter 4). Second, they have less-socially profitable investment opportunities because they have high levels of human capital already (Chapters 2 and 3). The greater the initial stock of human capital, the lower the potential marginal gains from investing in human capital. Hence, exploiting natural resources to finance human capital investments works better in developing economies. Paradoxically, it may be economically sensible for developed countries to forego or limit extracting natural resources if discovered, unless they are able to prevent political resource curses and process natural resources domestically (Chapter 4).

Conversely, resource-rich developing countries have a window of opportunity in which resource exploitation can improve economic prospects for future generations. The marginal benefits of produced- and human capital accumulation are high, while the marginal costs of natural capital depletion are low. Furthermore, global demand for their resources increases steeply due to the green transition. Hence, sustainable development is achievable for resource-rich countries. Nevertheless, caution is required: the success of extraction depends heavily on the quality of governance. The following sections elaborates.

6.2.2 Diversification of production and exports

Resource-rich countries must diversify their production, exports, and capital stock to fully harness natural resources for sustainable development. For three main reasons, natural resource exploitation cannot be a permanent route to sustainability.

1. First, it becomes increasingly harder to use natural resources to make net gains in inclusive wealth as human- and produced capital accumulate. The marginal benefits of investing natural resource revenues in human- and produced capital decrease while natural resources become scarcer, increasing marginal costs. However, the positive outlook is that countries need not rely on natural capital conversion for sustainable development as they become wealthier. They can meet their (future) needs using other forms of capital instead.
2. Second, the world is gearing up to move away from a linear production model and toward a circular economy. In a fully circular economy, global demand for new natural resources will be substantially lower than today. Accordingly, the linear to circular transition reduces the ability of natural resource-dependent countries to meet their needs by relying solely on natural resources. Resource exploitation is not a future-proof strategy for sustainable development, meaning timely diversification of production factors (i.e., capital assets) is key.
3. Third, as Chapter 4 demonstrates, an undiversified economy remains prone to political resource curses during the extraction phase, which can have a significant negative impact on sustainable development. These are unique to the natural resource sector. Similarly, resource exports hamper sustainable development in countries that do not fully specialize in the resource sector. Hence, an economy that relies on natural resource invites such issues more than an economy with a diversified composition of inclusive wealth.

The policy recommendation is that countries should view resource exploitation as a temporary development strategy. It is a springboard to prosperity in the period of linear production models and a global economy that transitions towards a greener future. The current global production model is linear because most minerals and metals come from exploitation (virgin materials versus recycled ones). However, in the future, humankind likely needs to switch to a circular economy that reuses materials and recycles products, reducing the need for new materials. Even though that transition could take decades, complacency and myopia are never ingredients of long-run success.

6.2.3 Transparency and accountability: The role of outside actors

Diversification is key for resource-rich countries in their window of opportunity. However, such a fundamental transforming an economy is challenging. Fortunately, several political and non-political entities can support the transition by hindering opportunistic behavior and strengthening natural resource taxation. Especially countries lacking the technical and institutional expertise to exploit natural resources require such external assistance.

Currently, it is common practice that governments grant exploration and extraction licenses that allocate the benefits of resource exploitation asymmetrically between the extracting company and the government. In this zero-sum game, the multinational companies that prospect and extract natural resources appropriate a disproportionally large share of revenues (Haufler 2010). These arrangements hurt current and future generations that live in the country that grants these rights. The asymmetry is likely the result of monopsony power and achieving a more balanced distribution is difficult when extraction companies benefit from weak institutions (Ostrowski 2020).

Expanding and empowering the Extractive Industries Transparency Initiative (EITI) is a potential solution. This NGO promotes open and accountable oil, gas, and mineral resource management (Extractive Industries Transparency Initiative 2023). The organization requires countries to implement EITI's exploitation standards. Furthermore, they can provide the technical assistance lacking in developing countries. Adopting these standards can empower countries to appropriate more resource rents. In turn, such funds can then be allocated toward growing inclusive wealth in countries suffering from reliance on multinationals.

Similarly, stakeholders in non-extracting countries can pressure the monopsonist multinational companies that abuse weak institutions. These companies are publicly owned, meaning that shareholders can use their voting power to enforce corporate social responsibility standards, such as the consent of the local community. However, extraction practices ignore these principles in their business models (Slack 2012). Shareholders can leverage their power over company executives to demand a better implementation of their principles in practice.

Similarly, countries hosting multinational headquarters can impose transparency that benefits the resource-rich country (Rauter 2019). Transparency can include, for example, mandatory disclosure of the special fiscal arrangements with resource-rich countries. The forced transparency can lead to new arrangements with a more symmetric allocation of revenues, thus curbing the monopsony power.

Rauter (2019) also suggests that public shaming and the threat of legal enforcement can deter abuse. Two suggested mechanisms are public shaming and the threat of legal enforcement of existing standards (Rauter 2019). These mechanisms may have worked in the cases of NGOs such as Urgenda and Milieudefensie in the Netherlands, which used litigation to defend the rights of future generations. All in all, several complementary actors outside of resource-exploiting countries' jurisdiction can curb extraction companies' (ab)use of market power.

6.3 Limitations

6.3.1 Measurement issues

At the core of this dissertation is the notion that sustainable development is a measurable phenomenon and that the growth of inclusive wealth is an accurate measurement of its economic dimension. Although the empirical work carefully considers the datasets, each has limitations involving measurement error, incompleteness, and misvaluations.

A shared limitation between the two data sources used—Genuine Savings and Inclusive Wealth— is that they do not include the complete range of economically valuable capital assets (Engelbrecht 2016; Roman and Thiry 2016). Human capital, in particular, is not only the product of a population's level of education but also its health.[2] The latter is not included in the datasets, even though health is important for estimating human capital (Arrow et al. 2012). Equivalently, social capital—described as the fabric of society (Putnam 1963, p. 249)—is not included in Genuine Savings, granted it is notoriously difficult to estimate. Inclusive Wealth estimates social capital indirectly by incorporating it in the shadow prices of capital. Yet, some are critical of whether said shadow prices truly measure social capital (Roman and Thiry 2016). Furthermore, the list of natural capital assets included is never complete, as one can always find more dimensions of the environment that are economically valuable. Consequently, omitting several capital assets means that capital stocks are undervalued.

2. One may argue that knowledge capital is another omitted capital stock. However, the Inclusive Wealth methodology accounts for knowledge indirectly via the shadow prices of human capital. Health, on the other hand, is simply lacking.

The undervaluation may generate three biases.

1. First, sustainable development is underestimated when the unmeasured capital assets accumulate. Vice versa, sustainable development is overestimated when they decumulate. The result is a potential amplification bias, where estimated correlations are overstated.
2. Second, using incomplete capital stocks as independent variables may result in an attenuation bias. It describes the phenomenon where the true slope depicting the relationship between an independent and dependent variable is steeper than the estimated one because changes in the independent variable are systematically undermeasured. The estimated impact is then less than the true effect.
3. Third, the systemic undervaluation of the independent variables means the true value exceeds the observed value. As a result, the error term contains systemic measurement error of the independent variable, leading to endogeneity.

Predicting the net effect of the three biases is near-impossible given that they work upward and downward simultaneously.

Even though measurement error affects all empirical studies, it is particularly relevant for this dissertation which employs datasets seeking to value *everything*; a monumental challenge that is always work-in-progress. Nevertheless, valuation methods are state-of-the-art at the time this dissertation's studies are conducted. Moreover, urgency in understanding sustainable development excuses measurement errors to some degree (Polasky et al. 2015).

6.3.2 Correlational evidence

Students learn that correlation does not equal causation. For instance, besides a strong correlation, there is little evidence that the number of Nicolas Cage movies in any particular year influences the number of drowning incidents in swimming pools.[3] Similarly, some studies in this dissertation consider correlations which are not proof of causation. For example, the negative correlation between the abundance of natural capital and the rate of sustainable development, found in Chapter 2, is insufficient for inferring a causal effect. In the same vein, Chapter 3's finding—that natural capital depletion correlates

3. This correlation is presented by a Harvard criminology student and can be found here (https://www.wnycstudios.org/podcasts/otm/articles/spurious-correlations).

positively with Inclusive Wealth growth rates—is not causal evidence. Even though several efforts, such as robustness checks and sensitivity analyses, aim to make causal interpretations of these results plausible, causal inference requires different methods. At best, the correlations are consistent with a hypothesized causal effect.

The standard approach to infer causality is by using plausibly exogenous variation, as has been done in Chapters 4 and 5. Exogenous variation prevents endogeneity because it assures that the independent variable is uncorrelated with the error term, which would lead to biased coefficients and interpretation issues. Specifically, Chapter 4 uses exogenous world prices and price volatilities to create shift-share instruments for endogenous natural resource variables (Bartik 1991). Similarly, Chapter 5 exploits a policy experiment to identify exogenous natural resource tax revenues. In these chapters, the exogeneity of temporal- or spatial variation helps identify the causal mechanisms.

However, addressing endogeneity for the *natural capital* variable is challenging. Researchers have used the timing and location of large natural resource discoveries (e.g., Cotet and Tsui 2013; Cust and Mihayli 2017; Tsui 2011). The rationale is that prospecting and discovering subsoil resources creates exogenous temporal and spatial variation in natural capital stocks. Researchers use both sources of variation to estimate the causal effects of natural capital on socioeconomic outcomes. However, there are two issues with using discoveries for causal inference. First, discoveries are country-specific, meaning it is challenging to generalize a true effect. The following limitation (Section 6.3.3.) elaborates on this issue. Second, the timing and location of discoveries are not truly exogenous (Brunnschweiler and Poelhekke 2021). Governments design prospecting policies and select discovery sites. Therefore, spatial- and temporal variation depends on countries' policies. The resulting endogeneity problem can bias outcomes.

Thus, correlational evidence at the cross-country level comes with the caveat that it is difficult to establish causality. Instruments for some natural resource variables exist, which Chapter 4 leverages. Nevertheless, valid and strong instruments or exogenous variation for other important variables (e.g., natural capital) are still lacking.

6.3.3 Generalizability of micro-studies

The benefits notwithstanding, micro-studies come with the caveat of generalizability. Take Chapter 5's case study of Indonesia, for example. This study is imperfectly reproducible or applicable to other countries because of Indonesia's unique institutional and geographical context. Indonesia's lower-level administrative units operate relatively autonomously compared to other countries. Indonesia is a vast archipelago with higher-level administrative units scattered, meaning they share less of the same culture, personal communication, and customs than would be the case if Indonesian provinces were connected by land. Although low-level units are decentralized and relatively autonomous, the central authority constraints their budgeting discretion, such as allowing a limited capacity for government debt. Chapter 5's results are partially attributable to these institutional and geographical features.

The implication is that policy recommendations from Chapter 5 are somewhat specific to Indonesia. Even countries such as Laos and Brazil, which are economically similar (e.g., resource-abundant, high income-growth rates, unsustainable development), cannot apply the recommendations seamlessly. Proposed policies may interact differently with these latter countries' geography and institutions, making outcomes unpredictable. Similarly, in a case study, such interactions are near-impossible to disentangle without relevant within-country variation. Comparative research is required.

6.3.4 Applicability of macro-studies

Similarly, one cannot directly apply generalizations from cross-country analyses (e.g., Chapters 2 and 3) to specific countries. Empirical results from regression analyses concern average effects. Quantile regression analyses (Chapter 2), moderating variables (Chapter 3), and sample splitting (Chapter 4) can further decompose results by finding averages for subgroups (i.e., cross-country heterogeneity). However, they always concern representative countries and never specific countries. As a result, decompositions become decreasingly informative.

The power of macro-studies is generalizability. However, it comes at the expense of country-specific applications. The implication is that policy prescriptions come with the caveat that macroeconomic insights may apply more to one country than another. The solution is to complement macro- with micro-studies. For instance, Chapter 4 identifies the general trend that governments, on average, tend to spend natural resource revenues on sustainable development. A case study confirms this generalization for the Indonesian context (Chapter 5).

6.3.5 Sustainability beyond economics

Finally, the topic of sustainable development is broader than how it is treated in economics, and by extension, in this dissertation. The thesis does not purport to comment on whether natural resource conversion is ecologically sustainable. There is a debate centering on the applicability of economics' capital approach to sustainable development (Ayres et al. 2001). Therefore, the conclusions, implications, and policy prescriptions gained through the four empirical studies only concern the ability to maintain economic prosperity throughout generations: economic sustainability.

Sustainable development can include social aspects that are absent in the capital approach. These include but are not limited to inequalities among groups based on gender, socioeconomic status, opportunities, and age. Such dimensions highlight essential aspects of a well-functioning society. Excessive within-country inequalities along any of these dimensions challenge the sustainability of the socioeconomic system. Dimension not considered in this dissertation are equally deserving of scholarly attention. Assessing sustainable development's economic component should not be the only, or even the leading consideration in some policy and academic debates.

6.4 Future research

6.4.1 How wealth composition drives sustainable development: Mechanisms

This dissertation finds that countries' inclusive wealth composition has been an overlooked determinant of sustainable development. Whereas the conventional wisdom is that more capital assets contribute to sustainable development at a decreasing rate (i.e., diminishing returns to capital accumulation), my studies suggest otherwise. The composition of Inclusive Wealth better predicts its growth rate than the overall (per capita) Inclusive Wealth stock. Furthermore, human capital seems to exhibit increasing returns. Potential explanations remain underexplored. A possibility is that interactions among capital types are important for explaining sustainable development.[4] In particular, human capital (and, to a lesser extent, social capital) appears necessary for becoming and remaining highly developed. There is an opportunity to link the existing research on human capital interactions (so-called human capital externalities) to the sustainable development literature.

6.4.2 Exporting sustainability: The role of international trade

An avenue for future research is to scrutinize the effect of international trade on sustainable development. Trade flows have increased steeply for decades alongside increasing global consumption and natural resource extraction (Schandl et al. 2017). Standard trade theory predicts that all parties gain from international trade. However, some criticize this conventional wisdom. Advocates of the theory of ecological unequal exchange claim that international trade between the Global North and South harms the latter (e.g., Hornborg 1998, 2014; Jorgenson 2016; Givens et al. 2019; Dorninger et al. 2021). An asymmetric distribution of the gains from trade in favor of the North masks the harm inflicted upon the South (Oleson 2011). This alternative view of trade is consistent with findings from Chapter 4.

The conjecture is that GDP does not capture the harm, but sustainable development metrics may. In other words, an untested hypothesis is that the Global North imports sustainability from the South. Extant work that correlates trade with sustainable development (measured by Genuine Savings) is likely spurious or plagued by endogeneity. Moreover, measuring trade flows has been imprecise, showing relative quantities, not patterns and relationships (Jorgenson 2016). Better identification strategies can evaluate whether international trade and natural resource flows affect sustainable development differently between importing and exporting countries.

6.4.3 Government resource revenue data (EITI)

Finally, I end with a recommendation for developing more precise government resource revenue data. Currently, governments are predominantly responsible for inclusive wealth investments. Policymakers need to collect more natural resource tax revenues and spend them productively to achieve effective natural resource conversion. However, the leading data source, the Government Revenue Dataset compiled by UNU-WIDER is rife for improvements.

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4. There is a direct link with the policy arena here. Several planning bureaus in The Netherlands (CPB, PBL, SCP) aim to create a model where the capital types interact, and how they determine broad welfare outcomes. The capital-type interactions that turn out to be so important in this thesis are at the cornerstone of their future efforts.

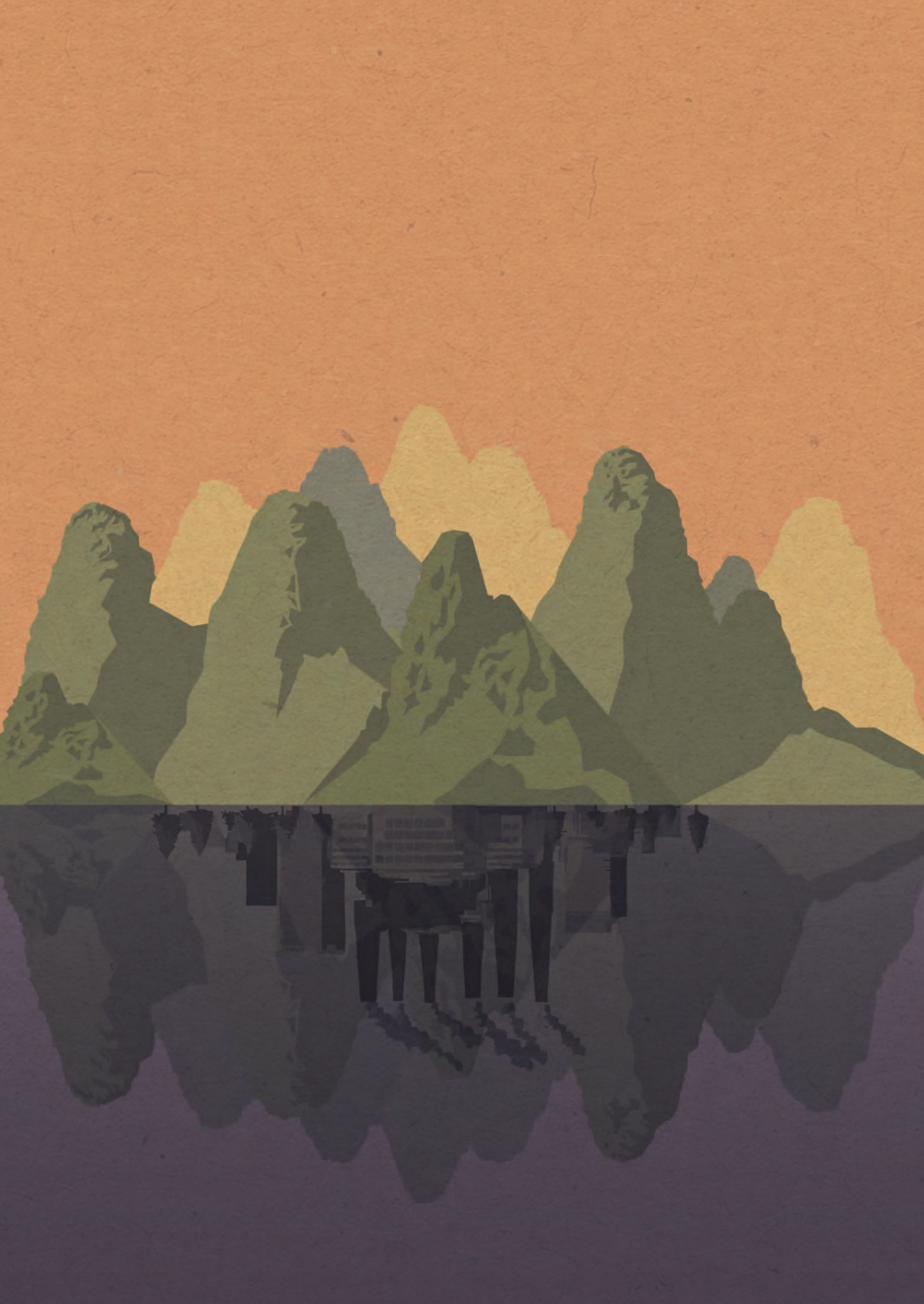
Ideally, revenue streams are comprehensive, accurate, and transparent, indicating which natural resources are exploited and what taxation schemes and special agreements exist. However, the opacity in the industry is a roadblock toward high-quality public data. Consequently, the Extractive Industry Transparency Initiative (EITI) can contribute by mandating sharing such data openly for researchers. Sharing these data could bolster accountability and have a direct positive effect on the efficiency of natural resource revenue spending. In addition, it would enable studying how natural resource revenues link to sustainable development in much-needed detail.

6.5 Concluding remarks

This dissertation progresses our understanding of how countries can exploit natural resources in a way that contributes to sustainable development. Natural richness is associated with worse sustainable development outcomes. Even though natural capital exploitation increases rates of sustainable development, resource-rich countries remain at an economic disadvantage. They are on unsustainable growth paths despite their impressive performances in terms of per capita GDP growth, a widespread yet less-apt measure of economic performance progress. Resource-rich countries face many obstacles on the way to effective resource conversion. Among these, myopia and opportunistic behavior by private and public actors can severely hamper future generations.

Several actions can be taken to address the obstacles. Governments can impose higher taxes on natural resources, uphold the rule of law, and aim beyond immediate political horizons. Firms and their stakeholders can honor or demand transparency, limiting monopsonic abuse. More broadly, key actors in societies, such as governments, academia, and media, can help deemphasize GDP and push for integrating better welfare indicators that consider all generations.

These actions are not wholly selfless for anyone. If future generations in resource-rich countries remain poor and dependent on natural resource exploitation, they remain incentivized to hinder and delay green solutions. Postponing green transitions can thus instigate a boomerang effect. It only aggravates harm not contained to those living in resource-exploiting countries.



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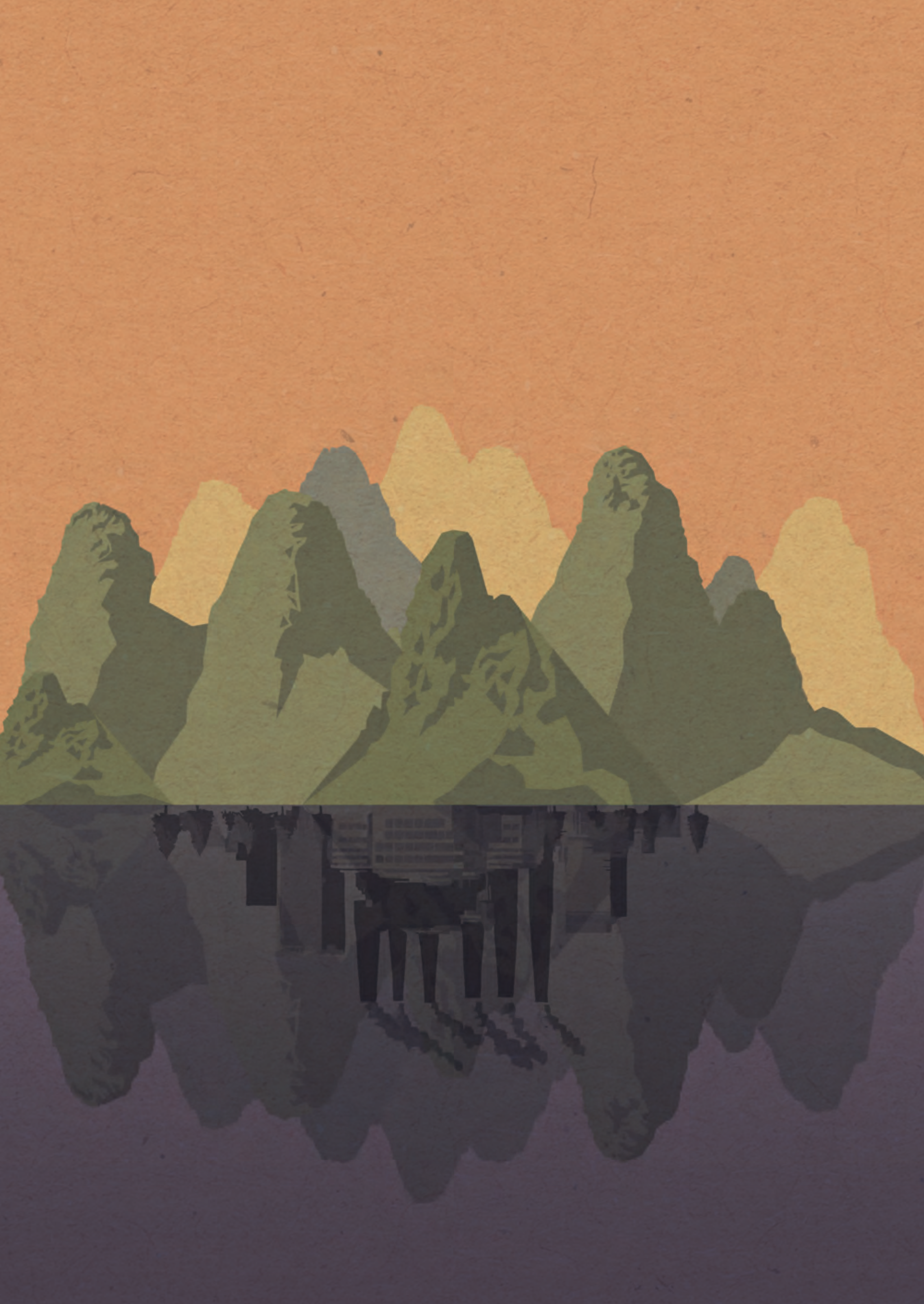


Appendix

Appendix to Chapter 2

Appendix 2A. Method of country categorization

I categorize countries following Ahmad et al.'s (2018) network-based frequency analysis that groups countries based on the relative abundance of types of capital. In short, the method compares every country with every other and links them when values are close. The country with the most links becomes the trend, and the country-distance from this trend (orbital distance) determines relative abundance. Based on this analysis, countries have high- or low values of each type of capital, corresponding to a relative abundance or scarcity. This chapter identifies three groups of countries based on the orbital distance at the beginning of the sample (1990). The first group—comprising 57 poor countries—scores low on all capital types. The natural capital-dependent group contains 30 countries that score low on produced- and human capital but high on natural capital. The 31 countries that score high on produced- and human capital can be considered rich economies independent of natural capital. The 22 remaining uncategorized countries are diverse and unused in the Blinder-Oaxaca analysis (Section 2.5.3 in the chapter). A time-invariant categorical variable indicates group membership, which takes a value of 1 for the poor, 2 for natural capital-dependent, and 3 for the rich countries. Table B1 in Appendix 2B lists all countries and indicates group membership.

Appendix 2B. List of countries and key data

Table B1. List of countries in sample and key data

	Dependent Variables		Main Independent Variables				Group Membership		
Country	Change in ln Per capita Inclusive Wealth (2010-1990)	Standardized change in Ln Inclusive Wealth (2010-1990)	Per capita Inclusive Wealth (ln)	Natural capital per capita (ln)	Human capital per capita (ln)	Produced capital per capita (ln)	Poor	Natural Capital-Dependent	Rich
Afghanistan	-0.155	-0.083	8.64	6.48	8.02	7.58	1		
Albania	0.150	0.010	10.46	9.14	9.47	9.44	1		
Algeria	-0.149	-0.037	10.74	9.97	9.48	9.37		2	
Argentina	0.064	-0.008	11.19	9.97	10.52	9.57		2	
Armenia*	0.204	0.041	9.87	6.67	9.57	8.36	1		
Australia	0.065	-0.018	13.09	12.08	12.35	11.26			3
Austria	0.225	0.044	12.78	8.98	12.43	11.49			3
Bahrain	0.161	0.048	11.70	9.19	11.23	10.47			
Bangladesh	0.278	0.051	8.35	5.97	8.11	6.23	1		
Barbados	0.124	0.002	12.28	7.50	12.04	10.70			
Belgium*	0.206	0.033	12.75	5.83	12.48	11.32			3
Belize*	-0.274	-0.068	11.54	11.19	10.02	8.87		2	
Benin*	-0.252	-0.059	9.65	8.95	8.78	7.22	1		
Bolivia	-0.414	-0.089	11.93	11.86	9.15	7.56		2	
Botswana	-0.038	-0.033	11.24	10.80	9.91	8.82		2	
Brazil	0.022	0.010	11.32	10.43	10.49	9.45		2	
Bulgaria	0.190	0.023	10.66	8.99	10.08	9.29	1		
Burundi*	-0.023	0.035	8.26	6.90	7.77	6.20	1		
Cambodia*	-0.267	-0.080	9.46	9.24	7.64	6.05		2	
Cameroon	-0.352	-0.070	10.35	9.92	9.02	7.89		2	
Canada	0.055	-0.031	13.07	12.05	12.37	11.13			3
Central African Republic*	-0.415	-0.084	11.07	11.03	7.29	6.93		2	
Chile	0.220	0.007	11.26	9.93	10.82	8.81		2	

	Dependent Variables		Main Independent Variables				Group Membership		
Country	**Change in ln Per capita Inclusive Wealth (2010-1990)**	**Standardized change in Ln Inclusive Wealth (2010-1990)**	**Per capita Inclusive Wealth (ln)**	**Natural capital per capita (ln)**	**Human capital per capita (ln)**	**Produced capital per capita (ln)**	**Poor**	**Natural Capital-Dependent**	**Rich**
China	0.385	0.052	9.69	8.83	8.99	7.22	1		
Colombia	-0.019	-0.002	11.20	10.47	10.29	9.03		2	
Congo, Dem. Rep.	-0.538	-0.113	10.33	10.21	8.01	6.37		2	
Congo, Rep.	-0.535	-0.093	11.63	11.56	6.96	8.78		2	
Costa Rica*	0.155	0.002	11.06	9.40	10.69	8.91	1		
Côte d'Ivoire	-1.06	-0.005	9.79	8.66	9.17	7.78			
Croatia	0.175	0.004	11.84	8.43	11.64	9.94			
Cuba	0.023	-0.007	10.4	7.82	10.05	9.26	1		
Cyprus*	0.193	0.015	12.22	7.45	12.01	10.55			3
Czech Republic	0.226	0.039	11.73	8.02	11.33	10.54			3
Denmark	0.097	-0.024	13.03	9.06	12.78	11.44			3
Dominican Republic	0.199	0.038	10.51	8.35	10.23	8.43	1		
Ecuador	-0.190	-0.036	10.64	9.99	9.38	9.01		2	
Egypt, Arab Rep.	0.127	0.023	9.46	7.85	9.09	7.25	1		
El Salvador*	0.312	0.057	10.06	7.28	9.77	8.41	1		
Estonia*	0.343	0.043	11.50	9.31	11.13	9.89	1		
Fiji*	0.138	0.058	10.67	8.98	10.26	8.78	1		
Finland	0.137	-0.001	12.88	10.40	12.48	11.51			3
France	0.215	0.027	12.75	8.46	12.46	11.31			3
Gabon	-0.339	-0.104	12.45	12.03	10.85	10.48			
Gambia, The*	0.005	0.019	8.73	7.79	8.14	5.91	1		
Germany	0.291	0.046	12.69	9.91	12.31	11.33			3
Ghana	-0.150	-0.025	9.29	8.37	8.34	7.75	1		

	Dependent Variables		Main Independent Variables				Group Membership		
Country	**Change in ln Per capita Inclusive Wealth (2010-1990)**	**Standardized change in Ln Inclusive Wealth (2010-1990)**	**Per capita Inclusive Wealth (ln)**	**Natural capital per capita (ln)**	**Human capital per capita (ln)**	**Produced capital per capita (ln)**	**Poor**	**Natural Capital-Dependent**	**Rich**
Greece	0.194	0.009	12.09	10.03	11.55	10.85			3
Guatemala	0.053	0.015	10.35	8.31	10.01	8.46	1		
Guyana	-0.019	-0.009	12.44	12.38	9.38	8.46		2	
Haiti*	0.183	0.063	8.45	4.52	8.22	6.78	1		
Honduras*	-0.125	-0.049	10.47	9.78	9.56	8.07		2	
Hungary	0.256	0.054	11.61	8.48	11.26	10.24			3
Iceland	0.004	-0.019	13.54	12.61	12.74	11.63			
India	0.148	0.021	9.27	7.95	8.83	6.88	1		
Indonesia	-0.004	0.000	10.03	9.35	9.18	7.40	1		
Iran, Islamic Rep.	-0.143	-0.034	11.31	10.97	9.61	9.05		2	
Iraq^	-0.588	-0.099	11.13	11.01	8.65	7.52		2	
Ireland	0.300	0.029	12.67	9.33	12.34	11.28			3
Israel	0.172	0.039	12.24	7.30	12.00	10.63			3
Italy	0.159	0.018	12.53	8.65	12.18	11.25			3
Jamaica	0.132	0.053	11.00	9.45	10.43	9.47	1		
Japan	0.179	0.044	12.80	8.10	12.42	11.62			3
Jordan	0.135	0.066	10.31	7.73	9.89	8.99	1		
Kazakhstan	0.063	0.032	11.41	10.89	9.91	9.72		2	
Kenya*	0.039	0.035	9.13	7.48	8.72	7.17	1		
Korea, Rep.	0.464	0.111	11.72	8.96	11.46	9.88			
Kuwait^	-0.279	0.139	13.44	13.32	10.88	10.07			
Kyrgyz Republic	0.029	0.024	8.96	8.04	7.89	7.62			
Lao PDR*	-0.304	-0.082	10.38	10.29	7.77	5.70		2	
Latvia*	0.340	0.021	11.09	8.82	10.74	9.43	1		
Lesotho*	0.176	0.079	9.41	4.51	9.20	7.70	1		
Liberia	-0.656	0.005	9.79	9.61	7.16	7.38		2	

Country	Dependent Variables		Main Independent Variables				Group Membership		
	Change in ln Per capita Inclusive Wealth (2010-1990)	Standardized change in Ln Inclusive Wealth (2010-1990)	Per capita Inclusive Wealth (ln)	Natural capital per capita (ln)	Human capital per capita (ln)	Produced capital per capita (ln)	Poor	Natural Capital-Dependent	Rich
Lithuania	0.245	0.013	11.20	8.27	10.84	9.83	1		
Luxembourg	0.297	0.009	13.05	7.89	12.74	11.72			3
Malawi*	-0.259	-0.004	8.50	7.82	7.32	6.79	1		
Malaysia	0.085	0.041	11.16	10.10	10.59	8.79		2	
Maldives	0.628	0.085	10.07	2.71	9.91	8.17			
Mali*	-0.320	-0.029	9.55	9.12	8.34	6.56	1		
Malta	0.326	0.038	11.79	6.06	11.64	9.81			3
Mauritania	0.055	0.011	9.86	8.00	9.53	7.79	1		
Mauritius*	0.254	0.029	10.78	7.16	10.59	8.87	1		
Mexico	0.179	0.022	11.11	9.38	10.58	9.69	1		
Moldova	-0.037	0.002	9.65	6.71	8.78	9.02			
Mongolia	-0.243	-0.054	11.57	11.47	8.67	8.49		2	
Morocco	0.219	0.060	10.15	7.69	9.84	8.43	1		
Mozambique	-0.488	-0.094	9.892	9.76	7.62	6.13		2	
Myanmar	-0.264	-0.043	9.06	8.90	7.09	4.21	1		
Namibia*	-0.156	-0.059	11.56	10.71	10.80	9.30		2	
Nepal	-0.316	-0.069	8.99	8.63	7.57	6.19	1		
Netherlands	0.184	0.012	12.74	9.03	12.43	11.35			3
New Zealand	0.094	-0.013	12.45	10.83	11.87	11.03			3
Nicaragua*	-0.124	-0.041	9.89	9.09	8.77	8.41	1		
Niger	-0.212	-0.031	8.81	7.37	8.19	7.31	1		
Nigeria	-0.362	-0.056	9.71	9.04	8.65	7.72	1		
Norway	0.059	-0.020	13.33	11.54	12.80	11.90			3
Pakistan	0.127	0.042	9.15	7.50	8.72	7.30	1		
Panama*	0.120	0.032	10.91	9.71	10.34	8.92		2	
Papua New			11.25					2	
Guinea	-0.547	-0.096		11.18	8.09	7.47			
Paraguay*	-0.225	-0.050	10.77	10.35	9.39	8.40		2	

	Dependent Variables			Main Independent Variables			Group Membership		
Country	**Change in ln Per capita Inclusive Wealth (2010-1990)**	**Standardized change in Ln Inclusive Wealth (2010-1990)**	**Per capita Inclusive Wealth (ln)**	**Natural capital per capita (ln)**	**Human capital per capita (ln)**	**Produced capital per capita (ln)**	**Poor**	**Natural Capital-Dependent**	**Rich**
Peru	-0.113	-0.040	11.29	10.90	9.79	8.96		2	
Philippines	0.098	0.030	9.47	7.45	9.02	7.98	1		
Poland	0.222	0.034	11.37	8.62	11.16	9.33			
Portugal	0.201	0.031	12.32	8.03	12.10	10.59			3
Qatar^	-0.754	-0.057	13.73	13.52	11.76	10.89			
Romania	0.204	0.046	10.84	8.99	10.35	9.38	1		
Russian Federation	0.028	-0.007	11.79	11.18	10.55	10.04		2	
Rwanda*	0.128	0.080	8.19	5.79	7.95	6.08	1		
Saudi Arabia	-0.271	-0.053	12.78	12.41	11.39	10.03			
Senegal	-0.205	-0.044	9.66	9.06	8.56	7.49	1		
Serbia*	0.146	0.031	10.82	7.71	10.63	8.79	1		
Sierra Leone*	-0.174	0.021	9.09	8.33	8.40	5.66	1		
Singapore*	0.371	0.050	12.13	2.40	11.87	10.67			3
Slovak Republic	0.204	0.017	11.51	7.99	11.13	10.26			3
Slovenia	0.254	0.048	12.15	9.20	11.84	10.60			3
South Africa	0.018	0.021	11.17	9.84	10.60	9.42	1		
Spain	0.377	0.083	12.39	8.64	12.06	11.01			3
Sri Lanka*	0.232	0.056	9.73	7.11	9.52	7.62	1		
Sudan	-0.316	-0.072	9.89	9.63	8.35	5.74			
Swaziland	0.063	0.049	10.77	7.93	10.42	9.35	1		
Sweden	0.125	-0.013	12.92	10.10	12.59	11.39			3
Switzerland*	0.086	-0.022	13.23	9.42	12.92	11.84			3
Syrian Arab Republic	-0.062	0.005	10.09	8.58	9.63	8.15			
Tajikistan	-0.201	-0.010	8.64	7.03	7.63	7.81	1		
Tanzania	-0.463	-0.078	9.12	8.92	7.05	6.14			

	Dependent Variables			Main Independent Variables			Group Membership		
Country	Change in ln Per capita Inclusive Wealth (2010-1990)	Standardized change in Ln Inclusive Wealth (2010-1990)	Per capita Inclusive Wealth (ln)	Natural capital per capita (ln)	Human capital per capita (ln)	Produced capital per capita (ln)	Poor	Natural Capital-Dependent	Rich
Thailand	0.246	0.094	10.13	8.50	9.61	8.59	1		
Togo	-0.123	-0.024	9.28	7.75	8.76	7.63	1		
Trinidad and Tobago	-0.043	-0.025	11.87	10.71	10.96	10.62			
Tunisia	0.223	0.042	10.48	7.89	10.13	8.99	1		
Turkey	0.179	0.047	11.05	8.74	10.77	9.13			
Uganda*	-0.067	-0.018	8.22	7.02	7.64	6.25	1		
Ukraine	0.076	0.031	10.57	9.49	9.58	9.33	1		
United Arab Emirates	-0.601	-0.128	13.79	13.28	12.36	11.96			
United Kingdom	0.169	-0.010	12.75	8.45	12.54	11.02			3
United States	0.118	-0.008	12.93	10.52	12.63	11.12			3
Uruguay*	0.147	0.015	11.20	9.37	10.83	9.30	1		
Venezuela, RB	-0.219	-0.064	12.07	11.52	10.78	10.13			
Vietnam	0.378	0.049	8.81	7.49	8.43	5.84			
Yemen, Rep.	-0.080	-0.037	9.73	8.69	9.17	7.22	1		
Zambia	-0.469	-0.083	10.84	10.73	8.17	7.51		2	
Zimbabwe	-0.226	-0.049	9.62	9.18	8.52	5.79	1		

Notes: Stocks of Inclusive Wealth, natural, produced, and human capital per capita are natural logarithms in 1990. An asterisk denotes missing exhaustible resource data either due to the inexistence of such resources in the country or unavailability of the source data. Per capita Inclusive Wealth change refers to the difference in log values between 2010 and 1990, which are used as the primary dependent variable for estimating β-convergence. Inclusive Wealth change relative to mean (2010-1990) denotes each countries' difference from the average global growth in that period. Negative (positive) values indicate a below (above) average change in the per capita log of Inclusive wealth

Appendix 2C. Sensitivity analysis: Baseline GDP models with alternative set of steady state control variables

Table C1. Sensitivity analysis: β-convergence estimations for per capita Gross Domestic Product growth with other control variables

	Dependent variable:				
	OLS (C1)	**OLS (C2)**	**SAR-OLS (C3)**	**SAR-OLS (C4)**	**SAR-FE (C5)**
Independent variables					
Gross Domestic Product (natural log)	-0.0019 (0.0011) [p=0.070]	-0.0025 (0.00087) [p=0.004]	-0.0022 (0.00094) [p=0.017]	-0.0020 (0.00094) [p=0.031]	-0.15 (0.0076) [p=0.000]
Control variables					
Population growth (%)		-0.0015 (0.0018) [p=0.425]		0.0028 (0.0016) [p=0.088]	N/A
Credit to financial sector		0.000007 (0.00004) [p=0.860]		0.000036 (0.00005) [p=0.480]	N/A
Government expenditures (% GDP)		-0.00011 (0.00006) [p=0.059]		-0.00024 (0.00022) [p=0.266]	N/A
Investment rate		0.00033 (0.00024) [p=0.182]		0.00043 (0.00023) [p=0.058]	N/A
Civil liberties score		0.0043 (0.0020) [p=0.036]		0.0060 (0.0026) [p=0.022]	N/A
Political rights score		-0.0042 (0.0021) [p=0.046]		-0.0059 (0.0022) [p=0.009]	N/A
Polity 2 score		-0.00080 (0.00056) [p=0.154]		-0.00067 (0.00049) [p=0.169]	N/A
Time fixed effects	Y	Y	N/A	N/A	Y
Spatial lag (dependent variable)			-0.34 (0.26) [p=0.194]	-0.37 (0.23) [p=0.111]	0.26 (0.14) [p=0.059]
N	548	351	137	76	548
#-countries	137	90	137	76	137
(Pseudo) R^2	0.090	0.095	0.256	0.358	N/A

Notes: The table reports standard OLS log-linear model to test β-convergence in annual growth rates of per capita Gross Domestic Product, conditionally and unconditionally. Standard errors are in parentheses. P-values are in square brackets. Models C1, C3, and C4 are identical to the baseline Models 1, 3 and 5 in Table 2.2. Models C2 and C4 used an alternative set of control variables taken from Kremer et al. (2022). The standard OLS models (C1) and (C2) cluster standard errors at the country level. The number of observations for the conditional beta convergence estimations in models (C3) and (C4) are lower due to missing control variable data. The spatial autoregressive model (SAR) with OLS does not allow repeated unit observations. Therefore, it considers one period of twenty years instead of four periods of five years. This reduces the number of observations and omits the time-fixed effects. The SAR fixed effects (FE) model contains no (time-invariant) control variables due to collinearity with the country-fixed effects. The SAR models use an inverse distance spatial weight matrix. The sample comprises 137 countries without steady state control variables and 90 countries with steady state control variables.

Appendix 2D. Spatial autocorrelation parameter: Moran's I

Table D1. Moran's I by year for Inclusive Wealth and Gross Domestic Product

Moran's I	1990	1995	2000	2005	2010
Per capita Inclusive Wealth (ln)	0.6338 (0.0647) [p=0.000]	0.6435 (0.0647) [p=0.000]	0.6565 (0.0647) [p=0.000]	0.6663 (0.0647) [p=0.000]	0.6725 (0.0647) [p=0.000]
Per capita GDP (ln)	0.2642 (0.0654) [p=0.000]	0.2708 (0.0654) [p=0.000]	0.2770 (0.0654) [p=0.000]	0.2752 (0.0654) [p=0.000]	0.2617 (0.0654) [p=0.000]

Notes: Moran's I is a measure indicating the presence of spatial autocorrelation. If the null hypothesis is rejected, it indicates that a spatial autoregressive model leads to more consistent results. The table is based on the inverse distance spatial weight matrix used in the main analyses.

Appendix 2E. Robustness Check: Addressing the dynamic panel bias

Table E1. Robustness Check: Bootstrapped-based bias corrected fixed effects estimates

	BCFE	**BCFE**
	Dependent variable: ln Inclusive Wealth$_{it}$	**Dependent variable: ln GDP$_{it}$**
Inclusive Wealth$_{t-1}$ [CI 99%]	1.329 (0.022) [1.273 – 1.385]	
Gross Domestic Product$_{t-1}$ [CI 90%]		0.854 (0.089) [0.706 – 1.001]
Country fixed effects	Yes	Yes
Time fixed effects	Yes	Yes
N	560	548
#-countries	140	137

Notes: The table shows estimates from the bootstrap-based bias corrected fixed effects model that addresses endogeneity arising in dynamic panel models. The standard Vos et al. (2015) algorithm is used. The independent variable is a lagged dependent variable. Standard errors are in parentheses. Confidence intervals are reported in square brackets. The confidence interval for GDP is set at 90% and for Inclusive Wealth at 99%. Steady-state controls are colinear with the country fixed effects and thus omitted.

Appendix 2F. Sensitivity analysis: Baseline Spatial Autoregressive models with contiguity spatial weight matrix

Table F1. Baseline results: β-convergence estimations for per capita Gross Domestic Product growth

	Dependent variable:	
	OLS	**OLS**
Independent variables		
Gross Domestic Product (natural log)	-0.0019 (0.0011) [p=0.070]	-0.0041 (0.0013) [p=0.001]
Control variables		
Population density in 1500		-0.00015 (0.00018) [p=0.416]
Timing of the use of plough		-0.010 (0.0060) [p=0.092]
Distance from the technological frontier in 1500 (natural log)		0.00022 (0.00066) [p=0.739]
Predicted genetic diversity		-0.019 (0.028) [p=0.503]
Number of domesticable animals		0.00035 (0.00088) [p=0.689]
Neolithic transition timing (natural log)		-0.0075 (0.0072) [p=0.298]
Ancestry-adjusted years since agriculture (in thousands)		0.0032 (0.0016) [p=0.043]
Population in 1000 (natural log)		0.0048 (0.0013) [p=0.000]
Time fixed effects	Y	Y
Spatial lag (dependent variable)		
N	548	360
#-countries	137	90
(Pseudo) R^2	0.090	0.109

Notes: The table reports standard OLS log-linear model to test β-convergence in annual growth rates of per capita Gross Domestic Product, conditionally and unconditionally. Standard errors are in parentheses. P-values are in square brackets. The standard OLS models cluster standard errors at the country level. The number of observations for the conditional beta convergence estimations in models are lower due to missing control variable data. The spatial autoregressive model (SAR) with OLS does not allow repeated unit observations. Therefore, it considers one period of twenty years instead of four periods of five years. This reduces the number of observations and omits the time-fixed effects. The SAR fixed effects (FE) model contains no (time-invariant) control variables due to collinearity with the country fixed-effects. The sample comprises 137 countries without steady state control variables and 90 countries with steady state control variables.

SAR-OLS	SAR-OLS	SAR-FE
-0.0022 (0.00091) [p=0.014]	-0.0045 (0.0016) [p=0.004]	-0.11 (0.0068) [p=0.000]
	-0.00011 (0.00017) [p=0.530]	N/A
	-0.0095 (0.0075) [p=0.202]	N/A
	0.00012 (0.0010) [p=0.907]	N/A
	-0.045 (0.042) [p=0.286]	N/A
	0.0012 (0.0010) [p=0.237]	N/A
	-0.0037 (0.0082) [p=0.650]	N/A
	0.0017 (0.0020) [p=0.388]	N/A
	0.0037 (0.0017) [p=0.033]	N/A
N/A	N/A	Y
0.14 (0.13) [p=0.256]	0.35 (0.14) [p=0.013]	0.18 (0.063) [p=0.004]
137	90	548
137	90	137
0.256	0.299	N/A

Table F2. Baseline results: β-convergence estimations for per capita Inclusive Wealth growth

	Dependent variable:	
	OLS	**OLS**
Independent variables		
Inclusive Wealth (natural log)	0.0019 (0.00046) [p=0.000]	-0.0022 (0.00054) [p=0.000]
Control variables		
Population density in 1500		0.00027 (0.000048) [p=0.000]
Timing of the use of plough		0.0066 (0.0026) [p=0.013]
Distance from the technological frontier in 1500 (natural log)		-0.0011 (0.00028) [p=0.000]
Predicted genetic diversity		-0.052 (0.013) [p=0.000]
Number of domesticable animals		0.0017 (0.00032) [p=0.000]
Neolithic transition timing (natural log)		-0.0088 (0.0022) [p=0.000]
Ancestry-adjusted years since agriculture (in thousands)		0.014 (0.0058) [p=0.015]
Population in 1000 (natural log)		-0.00098 (0.00040) [p=0.015]
Time fixed effects	Y	Y
Missing natural capital dummy	Y	Y
Spatial lag (dependent variable)		
N	560	364
#-countries	140	91
(Pseudo) R^2	0.056	0.479

Notes: The table reports standard OLS log-linear model to test β-convergence in annual growth rates of per capita Inclusive Wealth, conditionally and unconditionally. Standard errors are in parentheses. P-values are in square brackets. The spatial lag is based on a contiguity matrix. The standard OLS models cluster standard errors at the country level. The number of observations for the conditional beta convergence estimations in models are lower due to missing control variable data. The spatial autoregressive model (SAR) with OLS does not allow repeated unit observations. Therefore, it considers one period of twenty years instead of four periods of five years. This reduces the number of observations and omits the time-fixed effects. The SAR fixed effects (FE) model contains no (time-invariant) control variables due to collinearity with the country-fixed effects. The sample comprises 140 countries without steady state control variables and 91 countries with steady state control variables.

SAR-OLS	**SAR-OLS**	**SAR-FE**
-0.00031 (0.00076) [p=0.686]	-0.0025 (0.00088) [p=0.005]	-0.013 (0.0040) [p=0.001]
	0.00025 (0.000093) [p=0.007]	N/A
	0.00025 (0.000092) [p=0.071]	N/A
	0.0073 (0.0040) [p=0.039]	N/A
	-0.0011 (0.00054) [p=0.033]	N/A
	-0.047 (0.022) [p=0.010]	N/A
	0.0014 (0.00055) [p=0.032]	N/A
	-0.0088 (0.0041) [p=0.241]	N/A
	0.0012 (0.0010) [p=0.249]	N/A
N/A	N/A	Y
Y	Y	Y
1.05 (0.23) [p=0.000]	0.29 (0.24) [p=0.236]	0.32 (0.086) [p=0.000]
140	91	560
140	91	140
0.071	0.551	

Table F3. Decomposed results: β-convergence estimations for per capita Inclusive Wealth growth

	Dependent variable:	
	OLS	**OLS**
Independent variables		
Human capital (natural log)	0.0052 (0.00078) [p=0.000]	0.0038 (0.00071) [p=0.000]
Produced capital (natural log)	-0.00024 (0.00072) [p=0.736]	0.00060 (0.00073) [p=0.411]
Natural capital (natural log)	-0.0043 (0.00035) [p=0.000]	-0.0049 (0.00038) [p=0.000]
Control variables		
Population density in 1500		-0.00015 (0.000047) [p=0.001]
Timing of the use of plough		-0.0016 (0.0019) [p=0.412]
Distance from the technological frontier in 1500 (natural log)		-0.000032 (0.00028) [p=0.909]
Predicted genetic diversity		-0.037 (0.010) [p=0.000]
Number of domesticable animals		0.00093 (0.00025) [p=0.000]
Neolithic transition timing (natural log)		-0.0071 (0.0020) [p=0.000]
Ancestry-adjusted years since agriculture (in thousands)		0.0014 (0.00051) [p=0.006]
Population in 1000 (natural log)		0.0012 (0.00036) [p=0.001]
Time fixed effects	Y	Y
Missing natural capital dummy	Y	Y
Spatial lag (dependent variable)		
N	560	364
#-countries	140	91
(Pseudo) R^2	0.513	0.689

Notes: The table reports standard OLS log-linear model to test β-convergence in annual growth rates of per capita Inclusive Wealth, conditionally and unconditionally. Standard errors are in parentheses. P-values are in square brackets. The standard OLS models cluster standard errors at the country level. The number of observations for the conditional beta convergence estimations in models are lower due to missing control variable data. The spatial autoregressive model (SAR) with OLS does not allow repeated unit observations. Therefore, it considers one period of twenty years instead of four periods of five years. This reduces the number of observations and omits the time-fixed effects. The SAR fixed effects (FE) model contains no (time-invariant) control variables due to collinearity with the country-fixed effects. The SAR models use a contiguity spatial weight matrix. The sample comprises 140 countries without steady state control variables and 91 countries with steady state control variables.

SAR-OLS	SAR-OLS	SAR-FE
0.0066 (0.0011) [p=0.000]	0.0050 (0.0012) [p=0.000]	-0.059 (0.0099) [p=0.000]
-0.0022 (0.0010) [p=0.037]	-0.00054 (0.0011) [p=0.620]	-0.0004 (0.0020) [p=0.838]
-0.0041 (0.00039) [p=0.000]	-0.0050 (0.00053) [p=0.000]	-0.0084 (0.0028) [p=0.000]
	-0.00015 (0.000072) [p=0.032]	N/A
	-0.0022 (0.0029) [p=0.450]	N/A
	-0.000082 (0.00037) [p=0.826]	N/A
	-0.044 (0.015) [p=0.004]	N/A
	0.0011 (0.00037) [p=0.002]	N/A
	-0.0064 (0.0028) [p=0.024]	N/A
	0.0016 (0.00069) [p=0.024]	N/A
	0.0010 (0.00052) [p=0.054]	N/A
N/A	N/A	Y
Y	Y	Y
0.17 (0.13) [p=0.013]	-0.27 (0.16)	0.35 (0.083) [p=0.000]
140	91	560
140	91	140
0.646	0.803	

Appendix 2G. Sensitivity analysis: Baseline decomposed Inclusive Wealth analyses with interaction effects between capital types

Table G1. Decomposed results: β-convergence estimations for per capita Inclusive Wealth growth with interaction effect

	Dependent variable:	
	OLS	**OLS**
Independent variables		
Human capital (natural log)	0.017 (0.0016) [p=0.000]	0.015 (0.0018) [p=0.000]
Produced capital (natural log)	0.011 (0.0015) [p=0.000]	0.012 (0.0019) [p=0.000]
Natural capital (natural log)	-0.0042 (0.00034) [p=0.000]	-0.0045 (0.00035) [p=0.000]
Human capital × Produced capital	-0.0012 (0.00014) [p=0.000]	-0.0011 (0.00018) [p=0.000]
Control variables		
Population density in 1500		-0.000055 (0.00004) [p=0.216]
Timing of the use of plough		-0.00020 (0.0019) [p=0.917]
Distance from the technological frontier in 1500 (natural log)		-0.000095 (0.00026) [p=0.716]
Predicted genetic diversity		-0.026 (0.0098) [p=0.007]
Number of domesticable animals		0.00099 (0.00023) [p=0.000]
Neolithic transition timing (natural log)		-0.0053 (0.0018) [p=0.004]
Ancestry-adjusted years since agriculture (in thousands)		0.00046 (0.00052) [p=0.369]
Population in 1000 (natural log)		0.0014 (0.00034) [p=0.000]
Time fixed effects	Y	Y
Missing natural capital dummy	Y	Y
Spatial lag (dependent variable)		
N	560	364
#-countries	140	91
(Pseudo) R^2	0.557	0.722

Notes: The table reports standard OLS log-linear model to test β-convergence in annual growth rates of per capita Inclusive Wealth, conditionally and unconditionally. Standard errors are in parentheses. P-values are in square brackets. The standard OLS models cluster standard errors at the country level. The number of observations for the conditional beta convergence estimations in models are lower due to missing control variable data. The spatial autoregressive model (SAR) with OLS does not allow repeated unit observations. Therefore, it considers one

SAR-OLS	SAR-OLS	SAR-FE
0.018 (0.0024) [p=0.000]	0.014 (0.0026) [p=0.000]	-0.00019 (0.013) [p=0.988]
0.0079 (0.0022) [p=0.000]	0.0092 (0.0026) [p=0.000]	0.056 (0.0085) [p=0.000]
-0.0038 (0.00035) [p=0.000]	-0.0044 (0.00047) [p=0.000]	-0.0065 (0.0028) [p=0.000]
-0.0011 (0.00022) [p=0.000]	-0.0010 (0.00025) [p=0.000]	-0.0060 (0.0009) [p=0.021]
	-0.000063 (0.000068) [p=0.357]	N/A
	0.000035 (0.0026) [p=0.989]	N/A
	-0.00018 (0.00034) [p=0.591]	N/A
	-0.030 (0.013) [p=0.022]	N/A
	0.0012 (0.00033) [p=0.000]	N/A
	-0.0051 (0.0026) [p=0.047]	N/A
	0.00068 (0.00065) [p=0.300]	N/A
	0.0011 (0.00048) [p=0.020]	N/A
N/A	N/A	Y
Y	Y	Y
0.67 (0.21) [p=0.001]	-0.47 (0.29) [p=0.107]	0.51(0.18) [p=0.005]
140	91	560
140	91	140
0.698	0.826	

period of twenty years instead of four periods of five years. This reduces the number of observations and omits the time-fixed effects. The SAR fixed effects (FE) model contains no (time-invariant) control variables due to collinearity with the country-fixed effects. The SAR models use an inverse distance spatial weight matrix. The sample comprises 140 countries without steady state control variables and 91 countries with steady state control variables.

Table G2. Decomposed results: β-convergence estimations for per capita Inclusive Wealth growth with interaction effect

	Dependent variable:	
	OLS	**OLS**
Independent variables		
Human capital (natural log)	0.0051 (0.00078) [p=0.000]	0.0039 (0.00070) [p=0.000]
Produced capital (natural log)	-0.0024 (0.0018) [p=0.181]	-0.0061 (0.0017) [p=0.001]
Natural capital (natural log)	-0.0067 (0.0016) [p=0.000]	-0.011 (0.0015) [p=0.000]
Natural capital ×produced capital	0.00025 (0.00019) [p=0.185]	0.00074 (0.00017) [p=0.000]
Control variables		
Population density in 1500		-0.000089 (0.00005) [p=0.065]
Timing of the use of plough		-0.0016 (0.0019) [p=0.405]
Distance from the technological frontier in 1500 (natural log)		-0.00021 (0.00028) [p=0.445]
Predicted genetic diversity		-0.035 (0.0099) [p=0.001]
Number of domesticable animals		0.00089 (0.00025) [p=0.001]
Neolithic transition timing (natural log)		-0.0064 (0.0021) [p=0.002]
Ancestry-adjusted years since agriculture (in thousands)		0.0015 (0.00051) [p=0.005]
Population in 1000 (natural log)		0.00087 (0.00035) [p=0.014]
Time fixed effects	Y	Y
Missing natural capital dummy	Y	Y
Spatial lag (dependent variable)		
N	560	364
#-countries	140	91
(Pseudo) R^2	0.516	0.705

Notes: The table reports standard OLS log-linear model to test β-convergence in annual growth rates of per capita Inclusive Wealth, conditionally and unconditionally. Standard errors are in parentheses. P-values are in square brackets. The standard OLS models cluster standard errors at the country level. The number of observations for the conditional beta convergence estimations in models are lower due to missing control variable data. The spatial autoregressive model (SAR) with OLS does not allow repeated unit observations. Therefore, it considers one period of twenty years instead of four periods of five years. This reduces the

	SAR-OLS	SAR-OLS	SAR-FE
	0.0063 (0.0011) [p=0.000]	0.0050 (0.0011) [p=0.000]	-0.056 (0.010) [p=0.000]
	-0.0058 (0.0021) [p=0.006]	-0.0063 (0.0025) [p=0.013]	0.0016 (0.0057) [p=0.776]
	-0.0076 (0.0019) [p=0.000]	-0.0099 (0.0020) [p=0.000]	-0.0091 (0.0065) [p=0.158]
	0.00039 (0.00021) [p=0.058]	0.00065 (0.00025) [p=0.008]	-0.0001 (0.0007) [p=0.833]
		-0.000093 (0.000070) [p=0.187]	N/A
		-0.0012 (0.0027) [p=0.668]	N/A
		-0.00026 (0.00035) [p=0.462]	N/A
		-0.037 (0.014) [p=0.006]	N/A
		0.0011 (0.00035) [p=0.002]	N/A
		-0.0059 (0.0027) [p=0.027]	N/A
		0.0015 (0.00065) [p=0.020]	N/A
		0.00071 (0.00050) [p=0.161]	N/A
	N/A	N/A	Y
	Y	Y	Y
	0.65 (0.23) [p=0.004]	-0.48 (0.30) [p=0.111]	0.61 (0.17) [p=0.000]
	140	91	560
	140	91	140
	0.647	0.816	

number of observations and omits the time-fixed effects. The SAR fixed effects (FE) model contains no (time-invariant) control variables due to collinearity with the country-fixed effects. The SAR models use an inverse distance spatial weight matrix. The sample comprises 140 countries without steady state control variables and 91 countries with steady state control variables.

Appendix 2H. Additional figures on beta-convergence

This appendix presents some additional figures on beta-convergence.

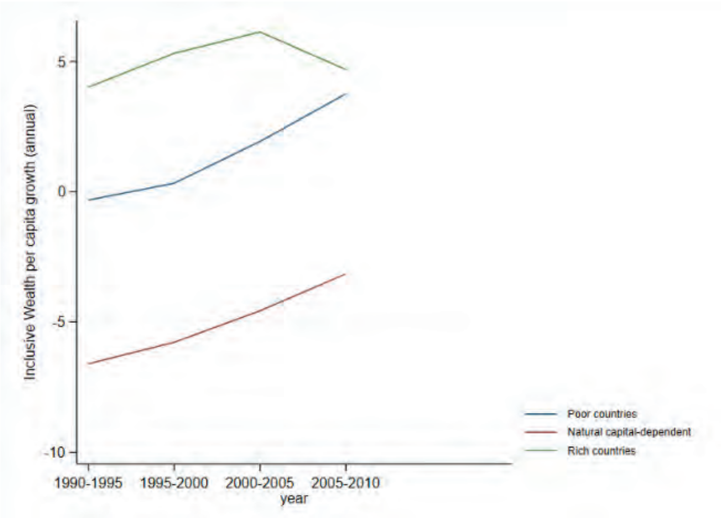


Figure H1. Inclusive Wealth growth by country-type

Notes: The graph indicates the average growth rate for a particular country group per year in the following 5-year period.

Figure H1 illustrates that growth rates are higher, on average, in rich countries than in natural-capital dependent and poor. The main analyses show that the difference between rich and poor is not statistically significant, especially in the period 2005-2010. However, natural capital-dependent countries sustainable development is substantially lower. Moreover, their negative coefficient shows that, on average, these countries have seen a decline in per capita wealth rather than an increase. Hence, they do not only underperform relative to the global mean, but they also shrink in absolute terms.

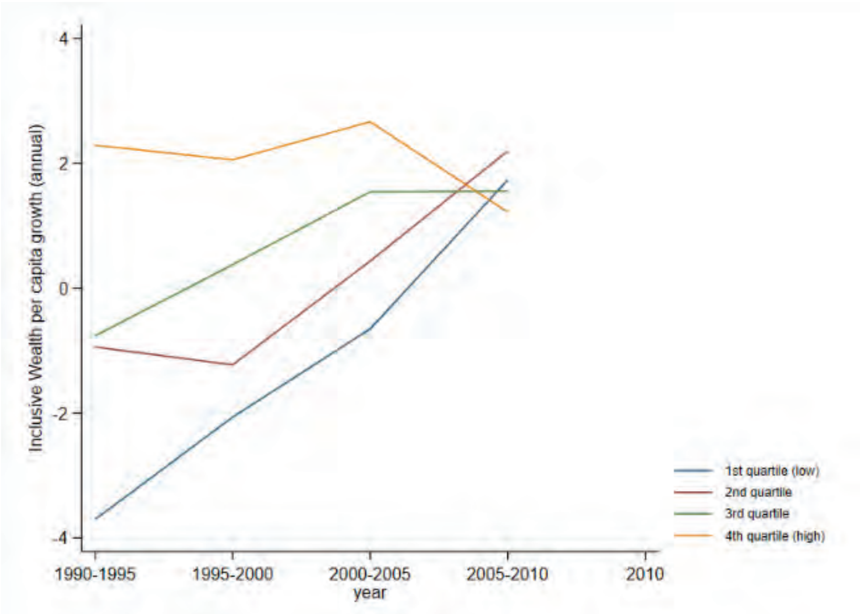


Figure H2. Inclusive Wealth growth by quartile

Notes: The graph indicates the average growth rate for a particular country group per year in the following 5-year period.

Figure H2 illustrates the rate of Inclusive Wealth growth per quartile. The figure shows that while rich economies grew faster initially in terms of per capita wealth, the advantage disappeared by the end of the sample period (2005 to 2010). Similarly, poor countries grew slower than others, but betas have equalized. Interestingly, this would imply that differences in growth rates vanished, suggesting that wealth inequalities do not exacerbate. However, the other analyses of the chapter and Figure H1 indicate substantial cross-country heterogeneity along other dimensions. Hence, it is not wealth differences but wealth composition that matters for wealth growth.

Appendix 2I. Country club membership for club convergence analysis

Table I1. Convergence club of Inclusive Wealth with Phillips-Sul algorithm

Club	Countries
1	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Kuwait, Luxembourg, Netherlands, Norway, Qatar, Spain, Sweden, Switzerland, United Arab Emirates, United Kingdom, United States
2	Barbados, Cyprus, Greece, Guyana, Israel, Korea, Rep., Malta, New Zealand, Portugal, Saudi Arabia, Singapore, Slovenia
3	Bahrain, Croatia, Czech Republic, Estonia, Gabon, Hungary, Poland, Russian Federation, Slovak Republic, Trinidad and Tobago, Venezuela, RB
4	Argentina, Belize, Bolivia, Botswana, Brazil, Chile, Costa Rica, Jamaica, Kazakhstan, Latvia, Lithuania, Malaysia, Maldives, Mauritius, Mexico, Mongolia, Namibia, South Africa, Turkey, Uruguay
5	Colombia, Congo, Rep., Iran, Islamic Rep., Panama, Peru, Romania, Serbia
6	Bulgaria, Fiji, Papua New Guinea, Swaziland
7	Albania, Algeria, Central African Republic, Cuba, Dominican Republic, El Salvador, Iraq, Jordan, Morocco, Paraguay, Thailand, Tunisia, Ukraine
8	Armenia, China, Ecuador, Guatemala, Honduras, Sri Lanka, Zambia
9	Cameroon, Indonesia, Lao PDR, Mauritania, Syrian Arab Republic
10	Benin, Congo, Dem. Rep., Cote d'Ivoire, Egypt, Arab Rep., India, Lesotho, Moldova, Nicaragua, Pakistan, Philippines, Senegal, Sudan, Vietnam, Yemen, Rep., Zimbabwe
11	Bangladesh, Cambodia, Ghana, Kenya, Kyrgyz Republic, Liberia, Mali, Mozambique, Nigeria, Togo
12	Gambia, The, Haiti, Myanmar, Nepal, Niger, Rwanda, Tanzania
13	Afghanistan, Tajikistan
14	Burundi, Malawi, Uganda

Appendix to Chapter 3

Appendix 3A. Additional sensitivity analyses

Sensitivity analysis A1: Controlling for missing exhaustible resource data

Natural capital comprises of renewable and exhaustible natural resources. The Inclusive Wealth Report, the data source, misses data on exhaustible resources for several countries. Some countries possess significant unreported fossil fuel or mineral deposits (e.g., Sierra Leone, Uganda, Rwanda), which may give a false positive indication of sustainability when converted into produced- and human capital (Hamilton 2012). This would inflate the coefficient of one or more predictors. I control for this issue by including a dummy variable indicating missing data that interacts with produced capital stock for countries.[1] Further, I distinguish between the stock of forest and agricultural resources, for which data are complete, and fossil fuels and minerals, for which data may be incomplete.

1. Alternatively, the coefficient of human capital accumulation can be inflated. To be complete, I interacted the dummy with human capital, and with both stocks in two separate estimations. No specification of the model resulted in different assessments of the hypotheses. I opted for reporting and discussing only one specification.

Table A1. Sensitivity analysis: The effect of capital accumulation on sustainable development (controlled for missing data)

	Dependent variable: per capita Inclusive Wealth growth (%)	
	Model 19	**Model 20**
Human capital	-0.261 (0.061) [p=0.000]	-0.266 (0.057) [p=0.000]
Produced capital (complete)	0.006 (0.023) [p=0.76]	0.005 (0.022) [p=0.20]
Produced capital (missing)	0.034 (0.01) [p=0.070]	0.040 (0.019) [p=0.03]
Fossil fuels and minerals		-0.000 (0.012) [p=0.999]
Forests and agriculture		-0.059 (0.017) [p=0.001]
Interaction terms		
Human capital * Resource-dep		
Human capital * Developed		
Produced capital * Resource-dep * (complete)		
Produced capital * Resource-dep * (missing)		
Produced capital * Developed * (complete)		
Produced capital * Developed * (missing)		
Fossil Fuels and Minerals * Resource-dep		
Fossil Fuels and Minerals * Developed		
Forests and Agriculture * Resource-dep		
Forests and Agriculture * Developed		
Country Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
*R*2-within	0.260	0.304

Notes: The table reports results for fixed-effects model. Standard errors (in parentheses) are robust standard errors that are clustered at the country level. P-values are reported in square brackets. The sample comprises 118 countries and 472 observations. Moderating effects are time-invariant country-types (developing, resource-dependent, developed). The main effect is omitted due to collinearity with country-fixed effects. Missing variable dummy (com) indicates the group of countries where exhaustible natural resources are reported, (mis) indicates the group of countries where they are missing.

	Moderating effect: Country-type			
	Model 21	Model 22	Model 23	Model 24
	-0.241 (0.064) [p=0.000]	-0.281 (0.055) [p=0.000]	-0.271 (0.058) [p=0.000]	-0.274 (0.055) [p=0.000]
	0.010 (0.021) [p=0.640]	0.013 (0.02) [p=0.646]	0.001 (0.022) [p=0.669]	0.009 (0.023) [p=0.706]
	0.045 (0.01) [p=0.014]	0.006 (0.033) [p=0.66]	0.041 (0.019) [p=0.030]	0.043 (0.020) [p=0.029]
	-0.006 (0.012) [p=0.636]	-0.006 (0.012) [p=0.640]	-0.025 (0.016) [p=0.131]	0.001 (0.012) [p=0.949]
	-0.046 (0.017) [p=0.007]	-0.042 (0.017) [p=0.014]	-0.046 (0.017) [p=0.007]	-0.060 (0.020) [p=0.003]
	0.04 (0.070) [p=0.492]			
	-0.223 (0.066) [p=0.001]			
		0.002 (0.040) [p=0.965]		
		0.074 (0.036) [p=0.044]		
		-0.104 (0.032) [p=0.001]		
		-0.029 (0.035) [p=0.410]		
			0.01 (0.019) [p=0.349]	
			0.059 (0.01) [p=0.002]	
				-0.023 (0.024) [p=0.348]
				0.035 (0.035) [p=0.311]
	Yes	Yes	Yes	Yes
	Yes	Yes	Yes	Yes
	0.340	0.351	0.328	0.311

Table A1 presents the results. Agricultural and forest resource depletion increases the rate of Inclusive Wealth growth, supporting Hypothesis 1. Fossil fuel and mineral depletion have no statistically significant effect except in developed countries. Model 23 shows that exhaustible resource depletion lowers Inclusive Wealth growth in developed economies. Furthermore, produced capital's predictor is indeed inflated. Although produced capital appears to increase the rate of Inclusive Wealth growth in countries where mineral and fossil fuel data are incomplete, this is likely the result of a bias. Produced capital neither has a statistically significant coefficient in any of the previous models nor for countries whose data are complete in this estimation.

Overall, this exercise strengthens the conclusion that natural capital depletion increases rates of Inclusive Wealth growth. The lack of consistent fossil fuel and mineral data prompts caution regarding claims about its effect on sustainable development.

Sensitivity analysis A2: Grouping countries based on institutional quality

To inspect whether grouping based on country type (developing, resource-dependent, developed) in the main analysis does not inadvertently capture some other unobserved property, I group countries based on several other dimensions. The first approach considers institutional quality as measured by government effectiveness and the rule of law from the Worldwide Governance Indicators (World Bank Group 2019). Specifically, I assess whether it provides a better moderating effect than country-type in the original analysis. Some argue that natural resource dependence is merely the result of deeply-rooted institutional heterogeneity across countries (Boos and Holm-Muller 2012; Brunnschweiler and Bulte 2008; Bulte et al. 2005; Lashitew and Werker 2020).

The main findings prevail.[2] Natural capital depletion fosters per capita Inclusive Wealth growth more in economies with low-quality institutions than ones with high-quality institutions. While being cautious in exclaiming a resource blessing, this finding starkly contrasts with the literature. For instance, whereas Mehlum et al. (2006) find that low institutional quality exacerbates the resource curse, this finding suggests that natural capital depletion fosters net wealth growth. The results do not support the idea that resource dependence leads to inferior institutions that, in turn, lower wealth growth.

2. Not reported in any tables.

Sensitivity analysis A3: Grouping countries based on income and geography

Furthermore, I group countries based on geography and the World Bank income classification system to identify low-, middle-low-, middle-high-, high-, and high-income OECD countries. The results show that produced, human, and natural capital accumulation do not affect rates of Inclusive Wealth growth differently among income classes, except for high-income and OECD countries. Results are comparable to repeating the exercise based on regions. However, a construct of three groups based on a particular mixture of income and location (i.e., high-income, Middle-East and Africa, and rest of the world) finds noteworthy results, reported in Table A2.

Table A2. Sensitivity analysis: The effect of capital accumulation on sustainable development: moderation by income-geography mix

Dependent variable: per capita Inclusive Wealth growth (%)			
	Moderating effect: Income-geography mixture		
	Model 25	**Model 26**	**Model 27**
Human capital	-0.285 (0.062) [p=0.000]	-0.292 (0.062) [p=0.000]	-0.092 (0.065) [p=0.161]
Produced capital	-0.002 (0.018) [p=0.899]	0.004 (0.017) [p=0.836]	0.002 (0.015) [p=0.896]
Natural capital		-0.043 (0.021) [p=0.044]	-0.049 (0.021) [p=0.018]
Human capital * High-income (0/1)			-0.437 (0.103) [p=0.000]
Human capital * Africa & M-E (0/1)			-0.173 (0.093) [p=0.066]
Produced capital * High-income (0/1)			
Produced capital * Africa & M-E (0/1)			
Natural capital * High-income (0/1)			
Natural capital * Africa & M-E (0/1)			
Country fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
R^2 within	0.155	0.174	0.270

Notes: The table reports results for fixed-effects model. Standard errors (in parentheses) are robust standard errors that are clustered at the country level. P-values are reported in square brackets. The sample comprises 140 countries and 560 observations. The reference category of the moderating variable is the group of countries 'Rest of the World', comprising all non-high-income countries outside of Africa and the Middle East. Africa and M-E denote countries in Africa and the Middle-East. High-income denotes all high-income countries in the World Bank's income classification system per 1990.

	Model 28	Model 29	Model 30
	-0.316 (0.061) [p=0.000]	-0.294 (0.064) [p=0.000]	-0.209 (0.096) [p=0.032]
	0.032 (0.020) [p=0.099]	0.002 (0.017) [p=0.910]	0.015 (0.022) [p=0.495]
	-0.026 (0.019) [p=0.162]	-0.117 (0.034) [p=0.001]	-0.051 (0.037) [p=0.163]
			-0.201 (0.0914) [p=0.029]
			-0.103 (0.145) [p=0.478]
	-0.158 (0.047) [p=0.001]		-0.103 (0.053) [p=0.053]
	-0.013 (0.024) [p=0.580]		0.005 (0.027) [p=0.845]
		0.126 (0.033) [p=0.000]	0.025 (0.047) [p=0.589]
		0.059 (0.028) [p=0.040]	0.017 (0.044) [p=0.700]
	Yes	Yes	Yes
	Yes	Yes	Yes
	0.283	0.228	0.302

Model 29 shows that natural capital depletion has a slightly less positive effect in Africa and the Middle East than other non-high-income countries. This regional disparity in the extent to which natural capital depletion is *beneficial* is the only glimpse my efforts yield that not all developing economies benefit equally from natural resource conversion. As with all preceding analyses, the results demonstrate that human capital accumulation lowers the rate of Inclusive Wealth growth, and all high-income countries report lower coefficients across the board.

Sensitivity analysis A4: Outliers

The main analysis is repeated while discarding potential outliers in the independent variables' observations. Outliers are identified when the decline of a capital stock in a specific period deviates clearly from the trend during other periods in that particular country. For instance, Moldova experienced a significant drop in human capital per capita between 2005 and 2010 despite moderate increases in the other three periods. Several countries show sharp temporary declines in produced capital per capita due to wars (e.g., Afghanistan, Iraq, Rwanda). Others experience sharp and fluctuating declines in natural capital, likely due to oil-related events (e.g., Bahrein, Liberia, Qatar) or other factors (e.g., Great Britain and Greece). I remove these observations (e.g., 12 countries) and repeat the main analysis to show that the conclusions are not driven by countries that have undergone such heavy shocks in their capital stocks. Some coefficients change slightly but the overall conclusions are robust.[3]

3. Not reported in any tables.

Appendix to Chapter 4

Appendix 4A. First stage regressions of the baseline analysis

Table A1. First stage regression of the baseline 2SLS analysis with all endogenous regressors (Table 4.4)

	First stage estimations	
	Model 9 (2SLS)	
	Energy rents (% of GNI)	**Energy exports (% of GNI)**
Instrumental variables		
Oil price instrument (real constant $)	0.006 (0.002) [p=0.001]	-0.002 (0.001) [p=0.000]
Gas price instrument (real constant $)	0.071 (0.052) [p=0.172]	0.104 (0.073) [p=0.162]
Coal price instrument (real constant $)	-0.000 (0.003) [p=0.986]	0.003 (0.005) [p=0.574]
Oil price volatility instrument	0.053 (0.021) [p=0.016]	0.146 (0.106) [p=0.175]
Gas price volatility instrument	0.000 (0.001) [p=0.747]	-0.003 (0.005) [p=0.543]
Coal price volatility instrument	-0.006 (0.002) [p=0.001]	0.019 (0.003) [p=0.000]
Independent variables		
Natural capital (natural log, per capita)	-0.034 (0.146) [p=0.815]	0.929 (0.458) [p=0.046]
Energy rents (% of GNI)	-	1.419 (0.196) [p=0.000]
Energy exports (% of GNI)	0.182 (0.065) [p=0.007]	-
Mineral rents (% of GNI)	0.049 (0.037) [p=0.190]	-0.231 (0.120) [p=0.058]
Forestry rents (% of GNI)	0.013 (0.009) [p=0.173]	-0.039 (0.030) [p=0.202]
Agricultural exports (% of GNI)	0.035 (0.030) [p=0.248]	-0.091 (0.095) [p=0.343]
Mineral exports (% of GNI)	-0.011 (0.013) [p=0.394]	0.013 (0.040) [p=0.751]
Government resource revenue (% of GNI)	0.363 (0.255) [p=0.160]	-0.124 (0.226) [p=0.586]

Model 10 (2SLS-FE)	
Energy rents (% of GNI)	**Energy exports (% of GNI)**
0.005 (0.002) [p=0.003]	-0.008 (0.003) [p=0.014]
0.105 (0.044) [p=0.020]	-0.196 (0.098) [p=0.050]
0.005 (0.002) [p=0.024]	-0.012 (0.005) [p=0.008]
0.052 (0.023) [p=0.028]	-0.018 (0.084) [p=0.836]
0.002 (0.001) [p=0.023]	-0.011 (0.003) [p=0.000]
-0.006 (0.003) [p=0.019]	0.019 (0.006) [p=0.003]
-0.376 (0.158) [p=0.020]	1.132 (0.541) [p=0.040]
-	1.582 (0.135) [p=0.000]
0.249 (0.053) [p=0.000]	-
-0.030 (0.043) [p=0.490]	-0.065 (0.080) [p=0.418]
0.010 (0.014) [p=0.480]	-0.060 (0.042) [p=0.161]
0.123 (0.066) [p=0.067]	-0.175 (0.178) [p=0.330]
-0.009 (0.010) [p=0.342]	0.023 (0.026) [p=0.383]
0.525 (0.358) [p=0.146]	0.478 (0.279) [p=0.091]

Table A1. Continued

First stage estimations		
	Model 9 (2SLS)	
	Energy rents (% of GNI)	**Energy exports (% of GNI)**
Time-varying control variables		
Produced capital (natural log, per capita)	-0.030 (0.104) [p=0.776]	-0.110 (0.331) [p=0.740]
Human capital (natural log, per capita)	-0.039 (0.085) [p=0.643]	0.414 (0.299) [p=0.170]
Per capita GDP (natural log, per capita)	0.199 (0.098) [p=0.046]	-0.340 (0.242) [p=0.163]
Rule of law	-0.175 (0.166) [p=0.296]	-0.073 (0.448) [p=0.872]
Government effectiveness	0.132 (0.209) [p=0.530]	-0.313 (0.583) [p=0.593]
Time invariant control variables	Yes	Yes
Time fixed effects	Yes	Yes
Country fixed effects	No	No
N	1231	1231
#-countries	77	77
R^2 *(within)*	0.929	0.857

Notes: The table presents the first stage for the baseline 2SLS(-FE) regressions presented in Table 4.4. Robust standard errors are clustered at the country level. The p-values are reported in square brackets. Relevant diagnostics are reported with the second stage.

	Model 10 (2SLS-FE)	
	Energy rents (% of GNI)	**Energy exports (% of GNI)**
	-0.698 (0.310) [p=0.027]	1.602 (0.781) [p=0.044]
	-0.125 (0.249) [p=0.616]	0.836 (0.519) [p=0.111]
	0.957 (0.303) [p=0.002]	-2.721 (0.901) [p=0.003]
	0.066 (0.180) [p=0.716]	-0.801 (0.645) [p=0.218]
	-0.116 (0.152) [p=0.446]	-0.066 (0.310) [p=0.833]
	N/A	N/A
	Yes	Yes
	Yes	Yes
	1231	1231
	77	77
	0.745	0.600

Appendix 4B. Descriptive statistics for sensitivity analysis

Table B1. Descriptive statistics for selected variables for enlarged sample

	Mean	Std. dev.	Min	Max
Genuine savings (% of GNI)	25.3	10.5	-28.7	62.2
Natural capital (real constant $, natural log, per capita)	8.84	1.14	4.13	13.3
Energy rents (% of GNI)	1.67	4.39	0	42.6
Energy exports (% of GNI)	5.16	10.7	0	76.2
Mineral rents (% of GNI)	0.389	1.16	0	14.2
Forestry rents (% of GNI)	1.04	3.19	0	41.4
Mineral exports (% of GNI)	0.935	1.34	0	13.4
Agricultural exports (% of GNI)	2.15	3.83	0	31.8
Government resource revenues (% of GNI)	1.67	4.39	0	42.6
Produced capital (real constant $, natural log, per capita)	9.98	1.69	5.29	12.9
Human capital (real constant $, natural log, per capita)	10.6	1.52	6.00	13.6
GDP (real constant $, natural log, per capita)	11.9	1.87	6.97	16.8
Rule of law	0.146	0.953	-1.87	2.12
Government effectiveness	0.204	0.935	-1.75	2.43

Notes: The descriptive statistics apply to the enlarged sample of Chapter 4, Section 4.4.4, Table 4.7.

Appendix to Chapter 5

Appendix 5A. Additional data and figures

Table A1. Correlation matrix for main variables

	Education	Oil and gas	Mining	Forestry	Fishing	Local taxation	DAU	DAK	Election year	Host regency
Oil and gas	0.048									
Mining	0.2741	0.055								
Forestry	-0.1955	0.1138	-0.1507							
Fishing	0.2335	0.2158	0.4774	-0.1804						
Local taxation	0.2411	0.4027	0.2305	-0.033	0.0906					
DAU	0.4243	0.1881	0.4464	-0.1515	0.4106	**0.7774**				
DAK	0.3474	0.066	0.378	-0.0749	0.2978	0.5383	**0.675**			
Election year	-0.1255	0.0934	0.0601	0.0111	0.0108	0.2021	0.1577	0.1671		
Host regency	0.1032	0.0135	0.1077	-0.0138	0.1176	0.1056	0.2355	0.2539	0.0621	
Offshoot regency	0.0101	0.0265	0.0877	-0.0245	0.0422	0.1489	0.17	0.1924	0.0595	-0.0387

Notes: The table presents Pearson's correlation coefficient between all major variables. Value in bold indicate a potential for multicollinearity. Removing local taxation, DAU, and/or DAK from the regression does not change coefficients or confidence intervals significantly.

Table A2. Data description

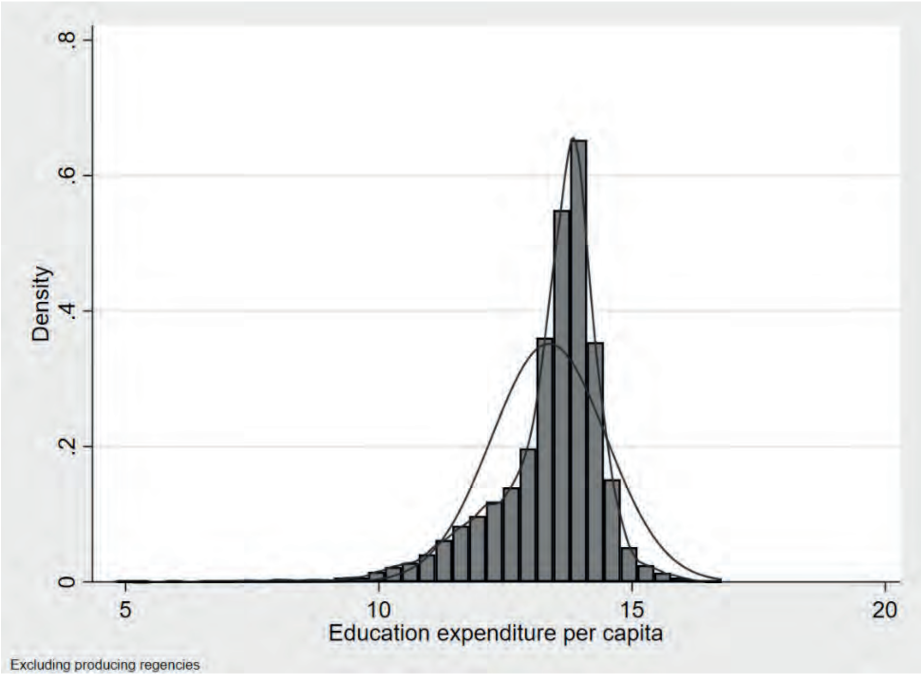
Variable	Description	Measurement
Dependent variables		
Education expenditure	Amount spent by regency budget on education function.	Natural log of per capita education expenditure in nominal annual Indonesian Rupiah (not PPP because domestic analysis)
Health expenditure	Amount spent by regency budget on health function.	Natural log of per capita health expenditure in nominal annual Indonesian Rupiah (not PPP because domestic analysis)
Economy expenditure	Amount spent by regency budget on economy function.	Natural log of per capita economy expenditure in nominal annual Indonesian Rupiah (not PPP because domestic analysis)
Environment expenditure	Amount spent by regency budget on environment function.	Natural log of per capita environment expenditure in nominal annual Indonesian Rupiah (not PPP because domestic analysis)
Tourism and culture expenditure	Amount spent by regency budget on tourism and culture function.	Natural log of per capita tourism and culture expenditure in nominal annual Indonesian Rupiah (not PPP because domestic analysis)
Public services expenditure	Amount spent by regency budget on public services function.	Natural log of per capita public services expenditure in nominal annual Indonesian Rupiah (not PPP because domestic analysis)
Order and security expenditure	Amount spent by regency budget on order and security function.	Natural log of per capita order and security expenditure in nominal annual Indonesian Rupiah (not PPP because domestic analysis)
Housing and public facilities expenditure	Amount spent by regency budget on housing and public facilities function.	Natural log of per capita housing and public facilities expenditure in nominal annual Indonesian Rupiah (not PPP because domestic analysis)
Independent variables		
Oil and gas revenues (shared)	Amount of oil and gas tax income of local governments (DBH Sumber Daya Alam).	Natural log of per capita natural resource sharing income from oil and gas in Indonesian Rupiah
Mining revenues (shared and local)	Amount of mining tax income of local governments (DBH Sumber Daya Alam).	Natural log of per capita natural resource sharing income from mining in Indonesian Rupiah
Forestry revenues (shared and local)	Amount of forestry tax income of local governments (DBH Sumber Daya Alam).	Natural log of per capita natural resource sharing income from forestry in Indonesian Rupiah

Variable	Description	Measurement
Fishery revenues (shared)	Amount of fishery tax income of local governments (DBH Sumber Daya Alam).	Natural log of per capita natural resource sharing income from fishery in Indonesian Rupiah
Fiscal control variables		
Central government income (DAU)	The amount of centrally provided tax income of local governments (DAU)	Natural log of per capita DAU income in Indonesian Rupiah
Special allocation fund Income (DAK)	The amount of centrally provided income for local governments intended for local provision of national priorities	Natural log of per capita DAK income in Indonesian Rupiah
Local tax income	The amount of locally collected tax income by local governments (DBH Pajak).	Natural log of per capita DHB Pajak income in Indonesian Rupiah
Political control variables		
Local election year	Dummy variable indicating local head election year (*Dupati election*)	1 for local election year, 0 for none
Host regency	Dummy variable indicating the source regency after proliferation	1 for host regency, 0 for none
Offshoot regency	Dummy variable indicating the offshoot regency after proliferation	1 for host offshoot, 0 for none
Moderating variable (interaction)		
Financial regulatory quality	Score on the quality of regency government's ability to uphold financial regulations and reporting practices by KKPOD	Standardized score
Institutional quality	Score on the quality of institutions in regency by KKPOD	Standardized score

Table A3. Descriptive statistics by regency groups

Variable	Mean			Median			Standard Deviation			Max			Min			N		
	Prod	Non-prod	Control	Prod	Non-prod	Control	Prod	Non-prod	Control	Prod	Non-prod	Control	Prod	Non-prod	Control	Prod	Non-prod	Control
Education	12.984	13.181	13.274	13.341	13.489	13.601	1.314	1.213	1.212	17.003	16.286	16.768	4.044	4.801	5.176	1257	1711	1515
Oil and gas	9.855	8.926	0	9.872	8.766	0	3.162	2.931	0	17.337	15.983	0	3.191	2.860	0	1257	1639	1580
Mining	6.982	6.815	8.357	6.585	7.113	9.260	4.126	3.462	3.864	16.336	16.419	15.380	0	0	0	1260	1706	1514
Forestry	2.939	2.618	1.860	2.406	0.855	0	3.282	3.135	2.899	12.918	13.217	13.354	0	0	0	1260	1706	1514
Fishery	6.816	6.360	6.148	6.367	6.202	6.160	2.197	2.528	2.951	14.596	14.550	13.815	0	0	0	1260	1706	1514
DAU	13.825	14.226	14.589	13.788	14.253	14.547	0.788	0.863	0.84	16.506	17.448	17.344	6.950	6.084	6.730	1258	1711	1520
DAK	11.680	12.205	12.774	11.568	12.212	12.836	1.210	1.271	1.250	15.421	16.399	15.970	4.956	4.892	5.214	1259	1703	1517
Local Taxation	12.005	12.134	12.032	12.041	12.170	12.043	0.963	0.95	0.933	15.466	14.579	15.680	4.150	4.968	4.096	1270	1714	1522
Election Year	0.067	0.13	0.196	0	0	0	0.25	0.337	0.397	1.000	1.000	1.000	0	0	0	1300	1760	1580
Host	0.061	0.097	0.157	0	0	0	0.239	0.296	0.364	1.000	1.000	1.000	0	0	0	1300	1760	1580
Offshoot	0.07	0.071	0.071	0	0	0	0.255	0.257	0.257	1.000	1.000	1.000	0	0	0	1300	1760	1580

Notes: The table presents summary statistics for main variables split by regency type, where 'Prod' refers to oil and gas producing regencies, 'Non-prod' refers to non-producing regencies in producing provinces sharing in oil and gas income, and 'Control' refers to regencies in non-producing provinces—the control group.



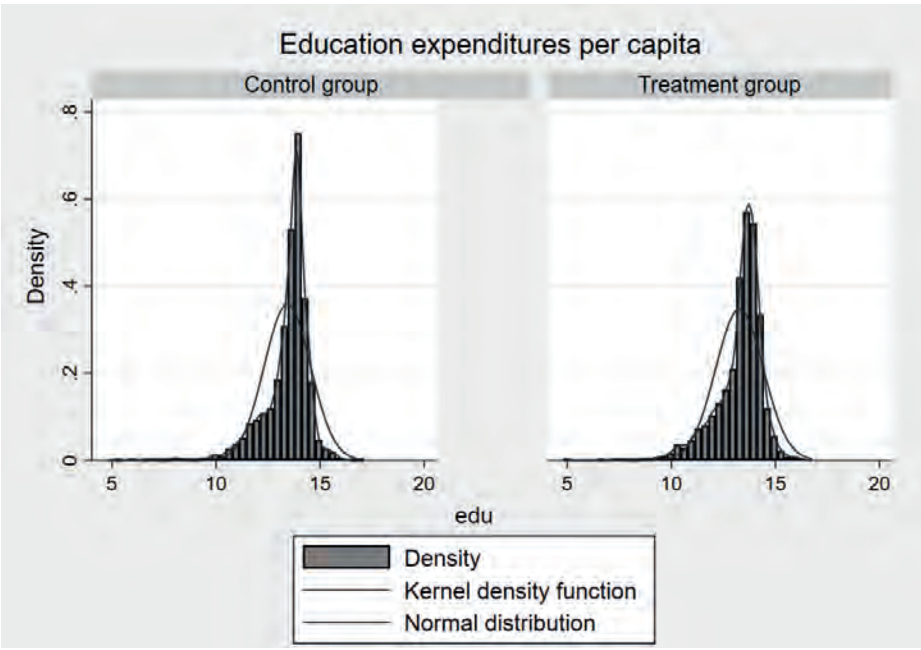


Figure A1. Histogram education expenditure

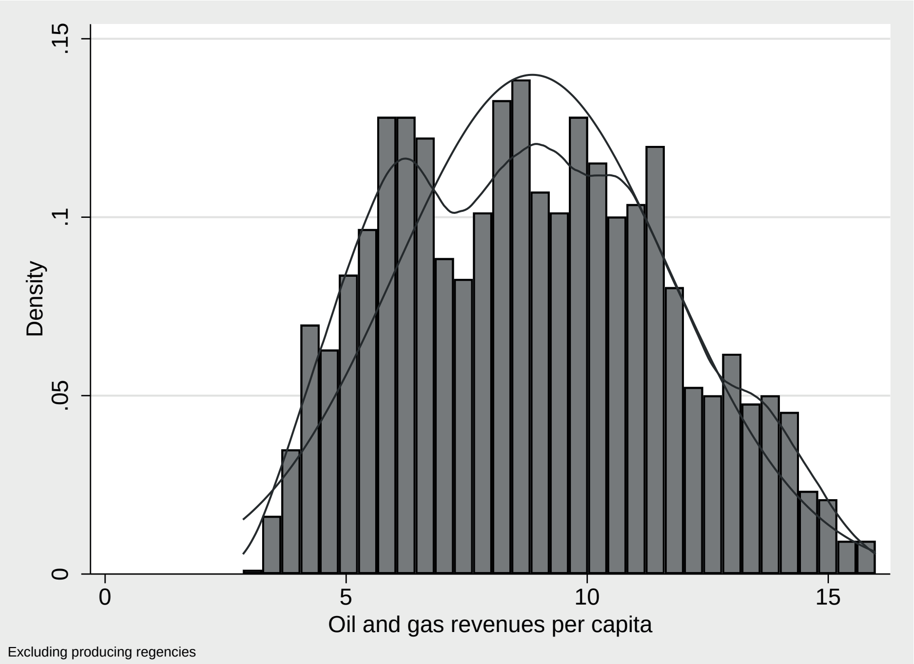


Figure A2. Histogram of oil and gas revenue

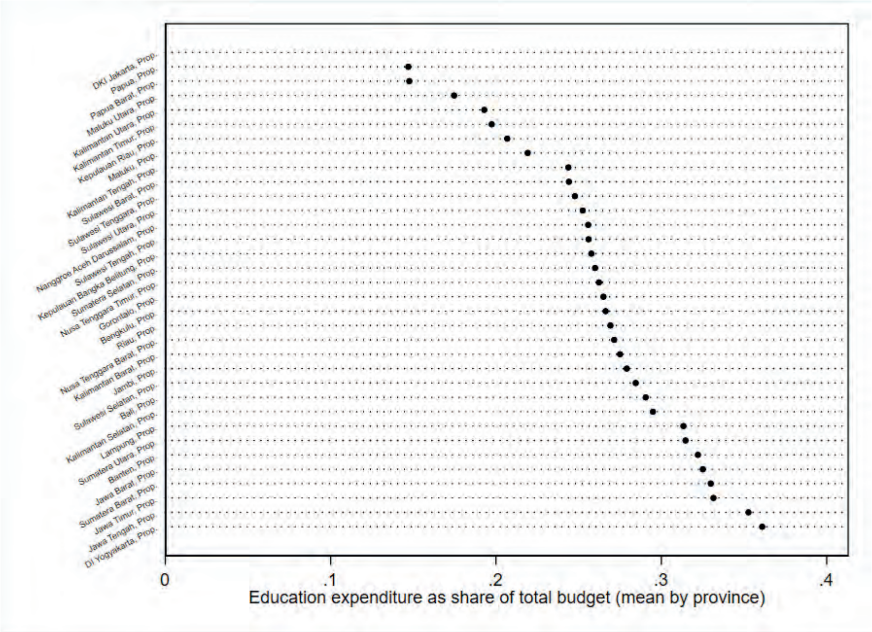


Figure A3. Mean regency education expenditure share by province

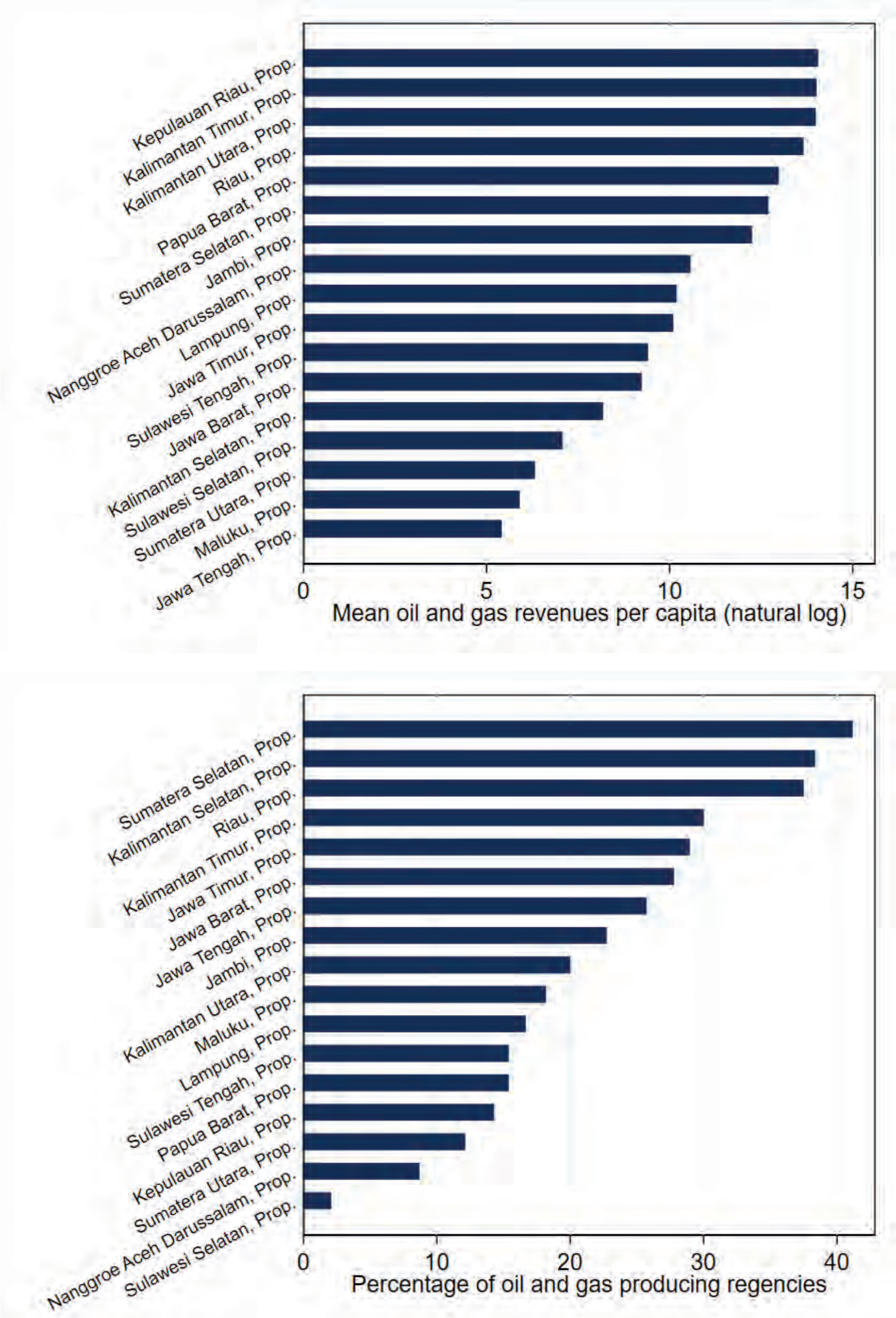


Figure A4. Histograms of regency oil and gas revenues per province

Appendix 5B. Sensitivity analyses for the baseline education results

Sensitivity to the tails of the distribution

I perform a range of sensitivity analyses. Table B1 below indicates to what extent the results are driven by regencies with higher oil and gas revenues per capita compared to those with low oil and gas revenues per capita. By excluding the top and bottom deciles, the results are as follows.

The coefficient is stable and similar to the baseline results throughout all iterations. The first two columns indicate the results without the top deciles. Removing these 345 observations and 20 regencies does not significantly alter our conclusions nor the precision of the estimations. However, removing the bottom deciles slightly widens the main independent variable's confidence intervals. Only when the bottom and top deciles are removed, and the sample shrinks significantly, does the significance level drop to 95%. Nevertheless, the results are robust: plausibly exogenous oil and gas revenue fluctuations increase education spending across the board.

Alternatively, another selection bias may be that regencies known for fiscal manipulation, such as ones taking advantage of the proliferation wave, can bias the estimations. Removing host and offshoot regencies (N = 2303, # of regencies = 261) produces a coefficient of 0.084 (0.026, p=0.000) and an R^2-within of 0.503; meaning that regencies suspect of political manipulation for revenue maximization spend comparatively more oil and gas revenues on education. This result does not support the idea that opportunistic behavior by government officials biases the results.

Table B1. Sensitivity analysis: Iterative exclusion of oil-and-gas deciles

	Dependent variable: natural log government education spending per capita					
	0-90	**0-80**	**10-100**	**20-100**	**10-90**	**20-80**
Fiscal revenue natural resources						
Oil and gas	0.107 (0.024) [p=0.001]	0.095 (0.024) [p=0.002]	0.092 (0.030) [p=0.027]	0.099 (0.034) [p=0.050]	0.110 (0.033) [p=0.016]	0.096 (0.039) [p=0.080]
Mining	-0.024 (0.012) [p=0.033]	-0.019 (0.012) [p=0.131]	-0.019 (0.012) [p=0.178]	-0.015 (0.014) [p=0.216]	-0.019 (0.012) [p=0.114]	-0.008 (0.014) [p=0.443]
Fishery	-0.033 (0.018) [p=0.321]	-0.040 (0.020) [p=0.274]	-0.042 (0.017) [p=0.092]	-0.042 (0.018) [p=0.072]	-0.043 (0.019) [p=0.130]	-0.050 (0.021) [p=0.094]
Forestry	0.023 (0.010) [p=0.001]	0.019 (0.010) [p=0.007]	0.015 (0.010) [p=0.004]	0.016 (0.010) [p=0.004]	0.017 (0.010) [p=0.004]	0.014 (0.010) [p=0.030]
Fiscal control variables						
DAK income	0.105 (0.039) [p=0.000]	0.113 (0.040) [p=0.000]	0.103 (0.036) [p=0.000]	0.136 (0.037) [p=0.000]	0.096 (0.040) [p=0.001]	0.142 (0.043) [p=0.000]
DAU income	-0.004 (0.063) [p=0.631]	-0.017 (0.062) [p=0.684]	0.016 (0.063) [p=0.433]	0.070 (0.065) [p=0.488]	0.005 (0.062) [p=0.534]	0.046 (0.062) [p=0.656]
Local tax Income	0.125 (0.058) [p=0.040]	0.126 (0.061) [p=0.060]	0.122 (0.056) [p=0.043]	0.113 (0.057) [p=0.047]	0.127 (0.060) [p=0.047]	0.119 (0.065) [p=0.079]
Political control variables						
Offshoot (0/1)	-0.779 (0.054) [p=0.000]	-0.774 (0.053) [p=0.000]	-0.741 (0.057) [p=0.000]	-0.750 (0.059) [p=0.000]	-0.755 (0.060) [p=0.000]	-0.750 (0.062) [p=0.000]
Host (0/1)	-0.417 (0.199) [p=0.145]	-0.455 (0.204) [p=0.126]	-0.404 (0.202) [p=0.173]	-0.440 (0.200) [p=0.149]	-0.391 (0.204) [p=0.182]	-0.471 (0.207) [p=0.132]
Election year (0/1)	0.097 (0.063) [p=0.466]	0.099 (0.065) [p=0.416]	0.127 (0.063) [p=0.213]	0.108 (0.065) [p=0.350]	0.115 (0.065) [p=0.415]	0.097 (0.069) [p=0.564]
Time FE	Y	Y	Y	Y	Y	Y
Regency FE	Y	Y	Y	Y	Y	Y
Observations	3091	2912	3067	2913	2901	2568
# regencies	346	335	355	353	346	335
Avg. years	8.9	8.7	8.6	8.2	8.4	7.7
R^2 within	0.424	0.436	0.396	0.393	0.403	0.413

Notes: The table presents fixed effect model estimates. The sample considered includes only non-oil and gas producing regencies so that oil and gas revenue is exogenous. Coefficients indicate point-elasticities. Standard errors in parentheses are clustered at the regency level. (0/1) indicates a dummy variable. Column names indicate range of observations included by deciles of oil and gas revenue, where 0-90 indicates only the top decile is excluded and 20-80 indicates the two top and two bottom deciles are excluded.

Sensitivity to omitted variable bias

While the within-regency variation in oil and gas revenues is plausibly exogenous, endogeneity may come into play when other time-varying factors are unobserved. Oster (2019) developed a technique to gauge the risk of omitted variable bias. In short, tracking the stability of the independent variable's coefficient and the explanatory power of the model (R^2) as potential confounders are added can say something about the likelihood that other yet-unobserved factors can explain away the statistically significant coefficient. The method assumes that for any model, there is a maximum potential explanatory power (R_{max}) when a hypothetical complete set of control variables is added, which is usually lower than $R^2 = 1$ due to reasons such as measurement error. In most empirical studies in economics, the unobserved set of control variables is usually smaller than the observed set of control variables. The ratio of observed to unobserved controls (δ) is assumed to have an upper bound of 1.

Table B2. Gauging omitted variable bias: Estimating the effects of unobservables on coefficient stability

Treatment variable	Baseline Effect (R^2)	Controlled Effect (R^2)	Null Rejected?	δ for β = 0 at R_{max} = 0.54	R_{max} for β = 0 at δ = 1
Oil and gas	0.2098 (0.017)	0.0958*** (0.416)	Yes	1.99	<0.70
DAK income	0.0798 (0.003)	0.1129** (0.416)	Yes	3.65	<0.95
Local tax Income	0.2089 (0.017)	0.1198* (0.416)	No	0.57	<0.49

Notes: The table shows the analysis of coefficient stability using Oster's method (2019). The baseline effect refers to a standard regression with education expenditure per capita as dependent variable and the treatment variable as the only independent variable. The controlled effect column refers to the results in the most complete baseline model of Table 5.3. The null rejected column indicates whether the null hypothesis is rejected in case the conceived maximum R^2 is set at 0.54 (= 1.3*R^2(.416), standard value suggested by Oster) and the ratio of controlled factors to unobservables is unity (δ = 1). The fifth column indicates what ratio (δ) is needed to reject the null and the sixth column indicates what R_{max} is needed to reject the null.

Table B2 presents the sensitivity analysis. The second column shows the coefficient and the model explanatory power in parentheses when excluding controls, and the third column shows these when including controls. By using this information, the fourth column indicates how large the share of unobserved control variables needs to be to potentially explain away the statistically significant coefficient for a standard R_{max}. If the result cannot be explained away for $\delta=1$, the null hypothesis is rejected (i.e., column three states 'Yes') and the coefficient is not at risk of the omitted variable bias. The fifth column shows the equivalent R_{max} needed to explain away the result potentially.

The analysis indicates that out of the three statistically significant budget variables—oil and gas revenues, DAK revenues, and local taxation—the first two are unlikely to suffer from omitted variable bias. Only if there are more than twice the number of time-variant unobserved control variables would it become possible that the true coefficient for oil and gas is zero. For DAK, this is even less likely. However, local taxation falls within the bounds, meaning that it is not immune to omitted variable bias. This does not imply that adding the unobserved controls necessarily flips the coefficient’s sign.

Sensitivity to influential observations

Finally, Table B3 displays the results when removing influential observations using the DF-beta statistic. This parameter shows when single observations disproportionately affect the coefficient.[4] I subsequently remove all influential observations, rerun the baseline regression, and test for coefficient stability, resulting in the most conservative estimates. The coefficient drops by more than 30%, but it is still positive and significant at the 99.9% level. It therefore seems that some observations created upward pressure on the coefficient, which may be the result of a measurement bias in the data, or these may have been the result of some valid but rare real-world phenomena. Furthermore, unobservables are unlikely to invalidate the new coefficient, confirmed by repeating Oster’s (2019) method. Hence, exogenous fluctuations in oil and gas revenues cause a significant increase in education expenditure, even in the most conservative estimations.

4. This is the case when the absolute value of the DF-beta statistic exceeds $2/\sqrt{N}(3257)$.

Table B3. Removing influential observations using DF-BETAS

Dependent variable: government spending on education per capita				
Treatment variable	**Baseline Regression Coefficient**	**Outliers Removed Coefficient**	**Difference**	**%-change**
Oil and gas	0.096 (0.022)	0.066 (0.013) [p=0.000]	-0.030	-31,3%
Mining	-0.024 (0.012)	-0.021 (0.010) [p=0.038]	0.003	12,5%
Fishery	-0.033 (0.017)	-0.033 (0.015) [p=0.027]	0.000	0%
Forestry	0.021 (0.010)	0.011 (0.009) [p=0.199]	-0.010	-47,6%
DAK	0.113 (0.036)	0.117 (0.034) [p=0.001]	0.004	3,5%
DAU	0.007 (0.063)	0.010 (0.049) [p=0.843]	0.003	42,9%
Local Taxation	0.120 (0.054)	0.146 (0.048) [p=0.003]	0.024	20%
Regency fixed effects	Yes	Yes		
Time fixed effects	Yes	Yes		
Control variables included	All	All	R_{max} for which $\delta = 1$	δ for which $R_{max} = 0.63$
Observations	3257	3112	>0.65	1.17
# regencies	355	355		
Avg. years	9.2	8.8		
R^2 within	0.416	0.487		

Notes: Robust standard errors clustered at the regency level are reported in parenthesis. The table compares the complete model of the baseline analysis from Table 5.3 to the equivalent model that excludes influential observations. Influential observations' absolute value for the DF-BETA statistic exceeds 0.00396 ($\approx 2/\sqrt{N(3257)}$). The table also reports δ and R_{max} values for associated unobservables needed to reject the null for the independent variable (oil and gas).

Appendix 5C. Replication analysis for healthcare investments

This section repeats the analyses for another essential component of human capital: health. Table C1 presents the baseline results with public healthcare expenditures per capita as the dependent variable. The findings indicate a positive and statistically significant impact of oil and gas tax revenues on healthcare expenditures. Specifically, I observe a point-elasticity of approximately 0.066, suggesting that a 1% increase in oil and gas tax revenues would lead to a 0.066% increase in healthcare expenditures. However, the healthcare coefficient is smaller than that for education, implying that natural resource windfalls are allocated more towards education than healthcare. If healthcare and education were equally important for regency leaders, one would find a higher elasticity for healthcare. This is confirmed in Table 5.7.

Table C1. Point-elasticity estimates of oil and gas revenues on healthcare expenditures

Dependent variable: natural log government healthcare spending per capita				
	(5)	**(6)**	**(7)**	**(8)**
Fiscal revenue natural resources				
Oil and gas	0.066 (0.017) [p=0.000]	0.070 (0.016) [p=0.000]	0.065 (0.017) [p=0.000]	0.065 (0.017) [p=0.000]
Mining		0.011 (0.009) [p=0.244]	0.005 (0.009) [p=0.554]	0.005 (0.009) [p=0.555]
Fishery		-0.010 (0.009) [p=0.277]	-0.012 (0.010) [p=0.233]	-0.012 (0.010) [p=0.236]
Forestry		-0.000 (0.006) [p=0.947]	-0.005 (0.006) [p=0.478]	-0.005 (0.006) [p=0.471]
Fiscal control variables				
DAK income			0.087 (0.028) [p=0.002]	0.089 (0.029) [p=0.002]
DAU income			0.054 (0.054) [p=0.319]	0.054 (0.054) [p=0.321]
Local tax Income			0.097 (0.039) [p=0.014]	0.101 (0.039) [p=0.011]
Political control variables				
Offshoot (0/1)				-0.116 (0.041) [p=0.005]
Host (0/1)				-0.139 (0.137) [p=0.312]
Election year (0/1)				0.027 (0.044) [p=0.551]
Time FE	Y	Y	Y	Y
Regency FE	Y	Y	Y	Y
Observations	3188	3108	3108	3108
# regencies	355	355	355	355
Avg. years per unit	9.0	8.8	8.8	8.8
R^2 within	0.345	0.341	0.349	0.349

Notes: The table presents fixed effect model estimates. The sample includes only non-oil and gas-producing regencies, so oil and gas revenue is exogenous. Coefficients indicate point-elasticities. The standard errors in parentheses are clustered at the regency level. (0/1) indicates a dummy variable.

Table C2 and C3 provide the sensitivity analyses to omitted variable bias and influential observations, respectively. First, the likelihood that oil and gas income does not increase healthcare expenditures is very low since the null is rejected. In other words, the set of unobservables needs to be implausibly large to potentially explain away the result of the baseline regressions in Table C1. After removing 144 influential observations, the findings remain intact, even though the coefficient decreases by 0.018 (a 23.7%p drop). Overall, the healthcare expenditures analysis echoes the insights from education: oil and gas tax revenues foster spending on human capital accumulation.

Table C2. Sensitivity of baseline healthcare results to omitted variable bias

Treatment variable	Baseline Effect (R^2)	Controlled Effect (R^2)	Null Rejected?	δ for $\beta = 0$ at $R_{max} = 0.46$	R_{max} for $\beta = 0$ at $\delta = 1$
Oil and gas	0.156 (0.024)	0.066 (0.349)	Yes	1.14	<0.56

Notes: The table shows the analysis of coefficient stability using Oster's method (2019). The baseline effect refers to a standard regression with education expenditure per capita as the dependent variable and the treatment variable as the only independent variable. The controlled effect column refers to the results in the baseline model of Table B1. The null rejected column indicates whether the null hypothesis is rejected in case the conceived maximum R^2 is set at 0.46 (= 1.3*R^2(.350), standard value suggested by Oster) and the ratio of controlled factors to unobservables is unity (δ = 1). The fifth column indicates what ratio (δ) is needed to reject the null, and the sixth column indicates what R_{max} is needed to reject the null.

In Table C4, I employ a spatial autocorrelation model that expands the baseline regression by incorporating regional spillovers of the dependent variable (healthcare expenditures), the independent variable (oil and gas revenues), and the error term. As a result, the confidence intervals for oil and gas revenues widen; however, the total effect (0.064; unreported) remains stable, as anticipated. In contrast to education, the best-fitting model for healthcare is more parsimonious, including only a spatial spillover of healthcare expenditures. This finding supports the political yardstick argument for public service provision, where local rulers compete to improve the quality of services. Moreover, the results suggest the absence of regional spillover effects of oil and gas revenue clustering or spatial clustering for errors.

Table C3. Removing influential observations using DF-BETAS

Dependent variable: government spending on healthcare per capita				
Treatment variable	**Baseline Regression Coefficient**	**Outliers Removed Coefficient**	**Difference**	**%-change**
Oil and gas	0.065 (0.017) [p=0.000]	0.047 (0.010) [p=0.000]	-0.018	-27,7%
Mining	0.005 (0.009) [p=0.555]	0.001 (0.008) [p=0.907]		
Fishery	-0.012 (0.010) [p=0.236]	-0.017 (0.009) [p=0.063]		
Forestry	-0.005 (0.006) [p=0.471]	-0.006 (0.006) [p=0.274]		
DAK	0.089 (0.029) [p=0.002]	0.090 (0.027) [p=0.001]	0.001	1,1%
DAU	0.054 (0.054) [p=0.321]	0.067 (0.057) [p=0.240]		
Local Taxation	0.101 (0.039) [p=0.011]	0.120 (0.033) [p=0.000]	0.018	18,8%
Regency fixed effects	Yes	Yes		
Time fixed effects	Yes	Yes		
Control variables included	All	All	R_{max} for which $\delta = 1$	δ for which $R_{max} = 0.55$
Observations	3108	2964	~0.57	1.10
# regencies	355	355		
Avg. years	8.8	8.3		
R^2 within	0.349	0.426		

Notes: Robust standard errors clustered at the regency level are reported in parenthesis. The table compares the complete model of the baseline analysis from Table C1 to the equivalent model that excludes influential observations. Influential observations' absolute value for the DF-BETA statistic exceeds 0.0359 (≈ $2/\sqrt{N(3108)}$). The table also reports δ and R_{max} values for associated unobservables needed to reject the null for the independent variable (oil and gas).

Table C4. Spatial autoregressive fixed effects models: Healthcare expenditures

	Spatial lag model (1)	Spatial lag model (2)	Spatial Durbin model
Main effects			
Fiscal revenue natural resources			
Oil and gas	0.054 (0.022) [p=0.015]	0.073 (0.029) [p=0.011]	0.057 (0.023) [p=0.014]
Mining	0.008 (0.009) [p=0.381]	0.006 (0.009) [p=0.533]	0.008 (0.009) [p=0.369]
Forestry	-0.009 (0.007) [p=0.194]	-0.008 (0.007) [p=0.222]	-0.009 (0.007) [p=0.227]
Fishery	-0.017 (0.011) [p=0.126]	-0.017 (0.011) [p=0.130]	-0.017 (0.011) [p=0.139]
Fiscal control variables			
DAK	0.043 (0.024) [p=0.075]	0.042 (0.024) [p=0.081]	0.043 (0.024) [p=0.076]
DAU	0.019 (0.037) [p=0.598]	0.019 (0.037) [p=0.604]	0.018 (0.037) [p=0.616]
Local taxation	0.056 (0.036) [p=0.123]	0.056 (0.036) [p=0.123]	0.059 (0.037) [p=0.112]
Political control variables			
Host	-0.078 (0.137) [p=0.570]	-0.080 (0.137) [p=0.559]	-0.085 (0.138) [p=0.539]
Offshoot	-0.055 (0.352) [p=0.875]	-0.024 (0.353) [p=0.945]	-0.028 (0.355) [p=0.937]
Year fixed effects	Yes	Yes	Yes
Regency fixed effects	Yes	Yes	Yes
Spatial autoregressive coefficient			
Health	0.201 (0.067) [p=0.003]	0.225 (0.071) [p=0.001]	0.159 (0.108) [p=0.142]
Oil and gas		-0.080 (0.077) [p=0.299]	
Error term			0.088 (0.161) [p=0.586]
Observations	2560	2560	2560
# regencies	256	256	256
Avg. years	10	10	10
AIC	3858.814	3859.736	3860.502
BIC	3975.769	3982.539	3983.305

Notes: The table presents the spatial fixed effects estimates for the non-oil and gas-producing regencies sample without missing observations between 2008 and 2017. All models include a spatial lag of the dependent variable. The second model adds a spatial lag of the independent variable. The third model includes a spatial lag of the error term. Standard errors are in parentheses.

In Table C5, I perform a mediation analysis by endogenizing local taxation and DAU (central government grants) using the model set-up illustrated in Figure 5.5. However, in this case, I Instead use healthcare expenditures as the dependent variable. Consequently, the second and third columns are unchanged compared to the model analyzing education expenditures.[5] The total effects show that oil and gas revenues substantially impact healthcare spending more than in previous estimations. This difference is due to the indirect effects via local taxation. Specifically, oil and gas tax revenues increase local taxation, which is then spent partially on healthcare. Notably, the total effect of DAK sharply drops because it crowds out DAU income, which raises questions about the efficiency of national budgeting policies. This is akin to spending on education: there appears to be a tax income substitution phenomenon. Hence, the problem with financing human capital investments centers more around central government failures than local preferences or squandering.

5. Indeed, the relationships between the exogenous independent variables and the endogenous budget components are unrelated to the choice of dependent variable in the second stage.

Table C5. Structural equation model mediation analysis: Healthcare expenditures

	Dependent variable: ln government healthcare spending per capita			
		Endogenous variable effects		
	(1) Direct effect	**(2) Indirect effect: Local tax income**	**(3) Indirect effect: DAU**	**(4) Total Effect**
Fiscal revenue natural resources				
Oil and gas	0.071 (0.014) [p=0.000]	0.046 (0.004) [p=0.000]	-0.002 (0.002) [p=0.316]	0.075
Mining	-0.007 (0.008) [p=0.377]	0.023 (0.005) [p=0.000]	0.024 (0.004) [p=0.000]	-0.001
Fishery	-0.008 (0.008) [p=0.357]	-0.041 (0.006) [p=0.000]	-0.048 (0.004) [p=0.000]	-0.019
Forestry	0.002 (0.005) [p=0.763]	-0.021 (0.006) [p=0.000]	-0.012 (0.005) [p=0.000]	-0.001
Fiscal control variables				
DAK income	0.128 (0.028) [p=0.000]	-0.094 (0.020) [p=0.000]	-0.428 (0.014) [p=0.000]	0.055
DAU income *(endogenous)*	0.149 (0.081) [p=0.065]			0.149 (0.081) [p=0.065]
Local tax income *(endogenous)*	0.094 (0.034) [p=0.005]			0.094 (0.034) [p=0.005]
Political control variables				
Offshoot (0/1)	-0.003 (0.238) [p=0.991]			-0.003 (0.238) [p=0.991]
Host (0/1)	-0.103 (0.112) [p=0.362]			-0.103 (0.112) [p=0.362]
Time FE		Y		
Regency FE		Y		
Observations		2784		
# regencies		355		

Notes: The table presents the generalized structural equation model corresponding to Figure 5.5. The sample considered includes only non-oil and gas-producing regencies, so oil and gas revenue is exogenous. The first column indicates the direct effect of the independent variables on education spending. The second and third columns indicate the estimation where local taxation and DAU are the dependent variables, respectively. The third column combines all into its total effects. Standard errors in parentheses are clustered at the regency level. (0/1) indicates a dummy variable.

Appendix D. Robustness Check: Alternative identification by regression discontinuity analysis

D1. Design and identification

The following sharp regression discontinuity analysis offers an alternative identification approach. It assesses whether there is a discontinuous jump in fiscal spending at land borders between non-producing and control regencies. The assumption underlying the analysis is that, absent the policy, the fiscal expenditure patterns would have evolved smoothly across the border. By exploiting the discontinuity in the revenue-sharing policy assignment, I can isolate the effect of the policy from other confounding factors that may influence the economic outcomes of the regencies.

The spatial regression discontinuity design compares units in a treated area to units in a control area. Treatment variable $T_i = 0$ for regencies located on the non-producing side of the land border and $T_i = 1$ for regencies on the producing side. The running variable is the distance from the relevant land border in kilometers, assigning a negative value on the non-producing side so that the cutoff is at 0.[6] Figure D1 presents the kernel density function of the variable.

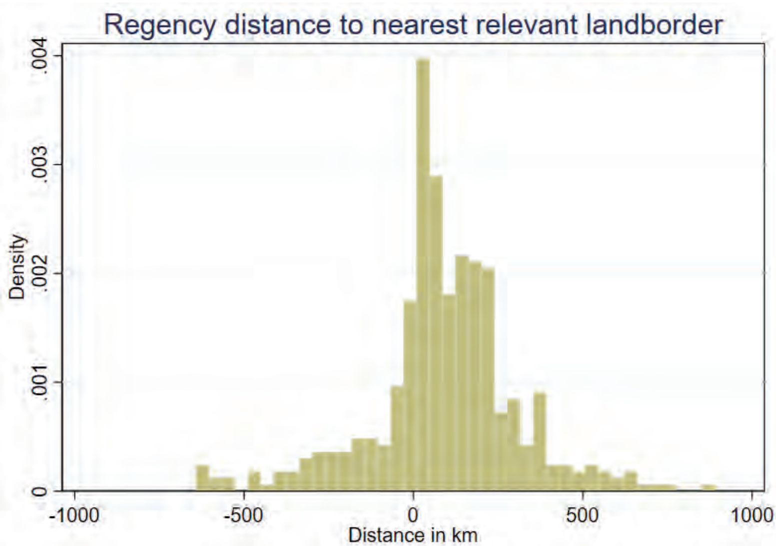


Figure D1. Histogram of distance from the closest relevant land border

6. Some regencies are closer to a land border on other islands than their own. In such cases, I calculate the distance to the nearest border on its own island, ensuring the current variable only captures land distance.

Figure D1 shows a seeming imbalance along the running variable; more regencies are on the producing than the non-producing side of the borders. The imbalance is not caused by manipulation of the assignment mechanism of the treatment because the selection of regencies into provinces took place much earlier than the design of the sharing policy. Regencies came into existence during the Dutch occupation and can only split within their province, and crucially, do not switch provinces. They cannot manipulate themselves into treatment. Similarly, provincial secessions between 2000 and 2004 and North Kalimantan's separation in 2012 were driven by ethnic sentiments. They can only self-selection out of treatment.[7] These cases of self-selection out of the treatment were perceived as economically disadvantageous. Hence, the imbalance is not the result of manipulation into treatment through self-selection.

The curvature of the land borders likely causes the imbalance in the running variable. Concavity implies more surface area on one side of the border, leading to an imbalance of regencies, in this case, favoring the producing side. The imbalance poses no risk to the identification strategy as long as there is no systematic bias in the assignment mechanism, for instance, if observations are unevenly distributed over time. The ratio of non-producing to producing-side regencies is roughly equal each year at around 0.3. Furthermore, control variables and sensitivity analysis concerning bandwidth selection and subgroup selection address any undetected potential biases.

An identifying assumption, the exclusion restriction condition, requires that the border does not elicit another effect other than the treatment. The condition could be violated in the presence of compound treatments, which is when provincial-level policies cause fiscal spending discontinuities at land borders. Although one can never guarantee to meet this condition, Indonesian fiscal laws dictate that provinces cannot not directly affect the regency fiscal revenues. The only higher administrative unit that affects regency-fiscal revenues is the central government through DAK and DAU funds. I control for these funds throughout the RDD analyses. The only potential confounder is when provincial

7. If we ignore the timing of secession, then there are three cases of self-selection out of treatment: Banten from Jawa Barat (2000), Riau Islands from Riau (2002), West Papua from Papua (2003). The loss of access to natural resource revenues garnered opposition to provincial proliferation, highlighting the perceived economic benefits of the treatment (Istania 2023). Additionally, West Sulawesi seceded from South Sulawesi in 2004, leaving the latter without oil and gas income, which can be considered voluntary self-selection out of treatment. However, South Sulawesi considered the split as economically beneficial (Istania 2023).

spending crowds out regency spending. What cannot be accounted for are sharp border discontinuities in fiscal spending preferences, which are unlikely to lead to a systemic bias provided there are eight relevant land borders. Hence, the exclusion restriction condition is likely met.

The sharp regression discontinuity analyses use the robust bias-correct inference method with the triangular kernel function (Calonico et al. 2020). The bandwidths are determined algorithmically using MSE optimization that minimizes variance as is standard in RDD analysis (Cattaneo and Titiunik 2022). The coverage error rate assesses how well the estimated confidence intervals for treatment effects cover the true treatment effect. It quantifies the coverage accuracy of these intervals, emphasizing the precision of the estimate). In both cases, I present the treatment effect's conventional and bias-corrected point estimator. The tables report both the conventional and the bias-corrected robust coefficients, the latter of which delivers better (usually larger) confidence intervals and more precise treatment estimates (Cattaneo et al. 2019).

D2. Baseline RDD results

Table D1. Sharp RD estimates for the impact of resource sharing on public service spending

Dependent variable	Conventional	Robust bias-corrected	Optimal bandwidth	N (untreated treated)
Education	0.603 (0.027) [p = 0.000]	0.632 (0.032) [p = 0.000]	44.3	3312 (219 507)
Healthcare	-0.092 (0.041) [p = 0.023]	-0.108 (0.044) [p = 0.013]	46.4	3319 (236 524)
Economy	-0.217 (0.034) [p = 0.000]	-0.224 (0.036) [p = 0.000]	46.4	3310 (235 523)
Environment	-0.287 (0.066) [p = 0.000]	-0.286 (0.081) [p = 0.000]	50.3	3263 (249 562)
Order & Security	-1.28 (0.069) [p = 0.000]	-1.33 (0.072) [p = 0.000]	18.3	3276 (112 150)
Tourism & Culture	-0.076 (0.095) [p = 0.424]	-0.099 (0.114) [p = 0.382]	116.3	2791 (334 932)
Public Services	-0.196 (0.028) [p = 0.000]	-0.179 (0.031) [p = 0.000]	68.1	3314 (316 749)
Social Protection	-0.261 (0.039) [p = 0.000]	-0.266 (0.040) [p = 0.000]	28.6	3284 (159 272)
Housing and Public Facilities	-0.106 (0.041) [p = 0.010]	-0.124 (0.042) [p = 0.004]	26.1	3309 (363 405)
Sustainable functions	0.041 (0.019) [p = 0.034]	0.033 (0.022) [p = 0.136]	57.8	3245 (283 622)
Current functions	-0.331 (0.042) [p = 0.000]	-0.337 (0.052) [p = 0.000]	92.6	2757 (287 766)

Notes: The table reports sharp regression discontinuity results where cells display the coefficient, standard error clustered at the regency level, and p-value, respectively. The coefficient confers the effect of being on the sharing side of the border (a positive coefficient means the policy increases spending). Analysis includes the standard vector of control variables without the natural log of oil and gas revenues per capita.

Table D1 presents the main results. Border distance is the continuous running variable. The left column indicates which fiscal spending function is the dependent variable. The results show that education expenditure stands out as the spending function increasing substantially as a result of the sharing policy. The positive coefficient indicates that receiving additional revenues increases education spending in absolute terms. The coefficient of 0.6 on a natural logarithmic scale, which is higher than most other coefficients combined with the fact that education is the largest expenditure function, means that the resource revenue sharing policy crowds in education spending while crowding out all other forms of spending. On average, this could indicate a slight increase in spending on sustainable development functions, although this effect is not statistically significant. Later estimations show a more robust effect when regencies are matched better (Table D4). Hence, the evidence suggests that the spending policy supports achieving sustainable development through education expenditures only.

Table D2 uses coverage error rate (CER) optimization to select bandwidths, which results in different coefficients and confidence intervals. There is no superior method between CER and the standard MSE (Cattaneo et al. 2019), yet MSE appears to be the default in most studies. Nevertheless, the table compares the results of the methods. The takeaway is that all effects are robust to the bandwidth selection method. Although changes in coefficients and standard errors are marginal, the CER method finds slightly different coefficients with lower statistical significance, especially for healthcare. Nevertheless, the stability of results does not depend on the optimization method.

Table D2. Sensitivity Analysis: Sharp RD estimates for the impact of resource sharing on public service spending with coverage error (CER) optimization bandwidth selection

Dependent variable	Conventional (MSE)	Robust bias-corrected (MSE)	Conventional (CER)	Robust bias-corrected (CER)
Education	0.603 (0.027) [p = 0.000]	0.632 (0.032) [p = 0.000]	0.593 (0.035) [p = 0.000]	0.607 (0.039) [p = 0.000]
Healthcare	-0.092 (0.041) [p = 0.023]	-0.108 (0.044) [p = 0.013]	-0.086 (0.054) [p = 0.111]	-0.096 (0.056) [p = 0.084]
Economy	-0.217 (0.034) [p = 0.000]	-0.224 (0.036) [p = 0.000]	-0.257 (0.046) [p = 0.000]	-0.261 (0.048) [p = 0.000]
Environment	-0.287 (0.066) [p = 0.000]	-0.286 (0.081) [p = 0.000]	-0.257 (0.080) [p = 0.001]	-0.266 (0.087) [p = 0.002]
Order & Security	-1.28 (0.069) [p = 0.000]	-1.33 (0.072) [p = 0.000]	-1.88 (0.068) [p = 0.000]	-1.91 (0.069) [p = 0.000]
Tourism & Culture	-0.076 (0.095) [p = 0.424]	-0.099 (0.114) [p = 0.382]	-0.160 (0.114) [p = 0.161]	-0.176 (0.126) [p = 0.164]
Public Services	-0.196 (0.028) [p = 0.000]	-0.179 (0.031) [p = 0.000]	-0.241 (0.037) [p = 0.000]	-0.231 (0.039) [p = 0.000]
Social Protection	-0.261 (0.039) [p = 0.000]	-0.266 (0.040) [p = 0.000]	-0.135 (0.90) [p = 0.135]	-0.135 (0.092) [p = 0.141]
Housing and Public Facilities	-0.106 (0.041) [p = 0.010]	-0.124 (0.042) [p = 0.004]	0.239 (0.068) [p = 0.000]	0.229 (0.069) [p = 0.001]
Sustainable functions	0.041 (0.019) [p = 0.034]	0.033 (0.022) [p = 0.136]	0.019 (0.24) [p = 0.427]	0.015 (0.026) [p = 0.574]
Current functions	-0.331 (0.042) [p = 0.000]	-0.337 (0.052) [p = 0.000]	-0.333 (0.057) [p = 0.000]	-0.338 (0.062) [p = 0.000]

Notes: The table reports sharp regression discontinuity results where cells display the coefficient, standard error clustered at the regency level, and p-value, respectively. The coefficient confers the effect of being on the sharing side of the border (a positive coefficient means the policy increases spending). The analysis includes the standard vector of control variables without the natural log of oil and gas revenues per capita. The MSE columns refer to the baseline analysis results of Table D1. The CER columns use coverage error rate optimization to select bandwidths.

D3. Sensitivity analysis: Regency selection using propensity score matching

To establish a true causal effect of the revenue sharing policy, the identification method requires that units that do and do not receive treatment are homogenous in other respects. Although there is no theoretical reason why regencies on the producing side of land borders differ from regencies on the non-producing side, I perform a sensitivity analysis by selecting and matching regencies based on their similarity regarding control variables. Accordingly, the selection rules out that observed systemic differences between regencies on either side of the border lead to the observed causal effect instead of the revenue sharing policy. I select regencies based on similarity using propensity score matching. Specifically, regencies-year observations are assigned a score between 0 and 1 based on their values for per capita government revenues from *DAU*, *DAK*, *local taxes, mining, fishery, forestry,* as well as whether countries are an offshoot or original from regency proliferation, and whether it is a local election year. I select all regencies-year combinations with a score above 0.8, ensuring that the regencies on each side of the border are nearly identical. Table D3 presents some descriptive statistics for the variables above.

Table D3. Selected descriptive statistics: Comparison between untreated and treated regencies with propensity score greater than 0.8

	Untreated regencies			Treated regencies		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**
Education expenditures	500	13.3	1.22	2,666	13.1	1.20
Central DAK revenue	999	12.9	1.58	5,376	12.7	1.61
Central DAU revenue	950	11.1	1.58	5,033	10.8	1.48
Local tax revenue	991	10.5	1.59	5,392	10.8	1.54
Mining	407	8.06	4.21	2,430	6.81	3.81
Fishery	407	6.10	2.80	407	6.10	2.80
Forestry	407	2.35	3.38	407	2.35	3.38
Offshoot regency (0/1)	1,951	0.043	0.203	7,475	0.015	0.120
Host regency (0/1)	1,951	0.051	0.221	7,475	0.017	0.129
Election year (0/1)	1,951	0.022	0.147	7,475	0.032	0.177

Table D4 presents the RDD results with the limited sample of regencies with a propensity score greater than 0.8. The results show statistically significant results for all expenditure functions except *Housing and Public Facilities* and the aggregate category *Current expenditure functions*. Generally, the results align more closely with the analyses in the main text. *Education*, *Social Protection,* and *Healthcare* emerge as expenditure functions that the revenue-sharing policy increases. Interestingly, the effect on education spending is double that of the baseline RDD design, highlighting that exogenous resource revenue flows significantly increase regional education spending in Indonesia. Spending categories where the initial negative coefficient turns positive are *Healthcare, Public Services,* and *Social Protection*, indicating that when comparing similar regencies on either side of the border, revenue sharing has a positive rather than a negative causal impact.

It is important to note that the coefficients of these spatial RDD estimates cannot be compared directly with the point-elasticity of oil and gas revenues from the main text. The latter estimates the effect of oil and gas only, whereas these estimates include potential variation in tax revenue flows from the other natural resources as well.

Table D4. Sensitivity Analysis: Sharp RD estimates for the impact of resource sharing on public service spending for limited regencies selected through propensity score matching

Dependent variable	Conventional	Robust bias-corrected	Optimal bandwidth	N (untreated treated)
Education	1.28 (0.204) [p = 0.000]	1.37 (0.240) [p = 0.000]	44.5	1712 (84 326)
Healthcare	0.288 (0.068) [p = 0.000]	0.321 (0.075) [p = 0.000]	64.3	1718 (96 421)
Economy	-0.073 (0.032) [p = 0.021]	-0.084 (0.036) [p = 0.019]	137.7	1710 (129 881)
Environment	-0.597 (0.110) [p = 0.000]	-0.569 (0.136) [p = 0.000]	46.8	1696 (83 337)
Order & Security	-0.555 (0.135) [p = 0.000]	-0.615 (0.150) [p = 0.000]	49.6	1691 (81 347)
Tourism & Culture	-0.642 (0.178) [p = 0.000]	-0.681 (0.210) [p = 0.001]	67.8	1430 (79 359)
Public Services	0.192 (0.078) [p = 0.013]	0.231 (0.085) [p = 0.007]	54.5	1713 (89 372)
Social Protection	0.557 (0.074) [p = 0.000]	0.608 (0.081) [p = 0.000]	44.9	1690 (79 326)
Housing and Public Facilities	-0.119 (0.098) [p = 0.225]	-0.078 (0.114) [p = 0.495]	45.2	1710 (83 333)
Sustainable functions	0.269 (0.053) [p = 0.000]	0.296 (0.058) [p = 0.000]	54.8	1682 (86 365)
Current functions	-0.158 (0.085) [p = 0.062]	-0.134 (0.098) [p = 0.173]	62.8	1408 (73 323)

Notes: The table reports sharp regression discontinuity results where cells display the coefficient, standard error clustered at the regency level, and p-value, respectively. Coefficient confers the effect of being on the sharing side of the border (positive coefficient = policy increases spending). Analysis includes the standard vector of control variables without the natural log of oil and gas revenues per capita. The sample is limited to regencies with a propensity score greater than 0.8 based on the control variables.

D4. Robustness Check: Regression with geographically proximate regencies and province-fixed effects

Table D5 presents an alternative approach for studying the discontinuities of eight distinct land borders across five large Indonesian islands. I calculate the geographical distance from the nearest relevant land border and limit the sample to non-producing regencies whose centroid is within 50km and 100km of the border, ensuring the exclusion of non-bordering regencies situated far away from the actual border. Provincial fixed effects cancel all other jumps at the policy border and between provinces with the same treatment outcome.

The positive effect of the policy—shared resource tax revenues—persists in the estimation. However, the heterogeneity analysis reveals that the positive effect only holds for four out of five islands in the archipelago, notably Sumatra, Kalimantan, Sulawesi, and Papua. The border jump is actually negative in Java. The 50km estimation results show that the lower net positive effect is 0.288 (Sumatra), whereas the highest is 0.808 (Papua). A pattern emerges where non-producing regencies on the wealthier islands generally benefit less, or in Java's case, suffer from the policy. This evidence is consistent with earlier findings from Chapters 2 to 4 that natural resource extraction can be a springboard for sustainable development but not indefinitely.

The effect and the model lose statistical significance when expanding the sample to non-producing regencies within 100 kilometers of the border. Only the island heterogeneity remains visible, but the model's explanatory power is relatively weak (R^2 decreases sharply), meaning other confounders are likely at play. A sensitivity check shows that distance from the border (on both sides) strongly predicts spending: the farther away from borders, the less is spent. Small distances, therefore, offer the most reliable results and conform to the main analysis.

Table D5. Natural resource sharing estimates within a subsample of regencies with border proximity

	Dependent variable: Education spending per capita (ln)				
		< 50km	**< 50km**	**< 100km**	**< 100km**
Producing province (0/1)		0.741 (0.127) [p=0.000]	-0.552 (0.132) [p=0.000]	0.483 (0.310) [p=0.122]	-0.659 (0.278) [p=0.019]
Closest border	*Java*		*ref*		*ref*
	Sumatra		1.292 (0.181) [p=0.000]		1.142 (0.196) [p=0.000]
	Kalimantan		0.840 (0.128) [p=0.000]		2.073 (0.325) [p=0.000]
	Sulawesi		1.334 (0.336) [p=0.000]		0.989 (0.274) [p=0.000]
	Papua		1.360 (0.127) [p=0.000]		1.141 (0.177) [p=0.000]
Province fixed effects		Yes	Yes	Yes	Yes
Year fixed effects		Yes	Yes	Yes	Yes
Adjusted R^2		0.518	0.518	0.114	0.114
N		894	894	1462	1462
# regencies		78	78	126	126

Notes: The table presents pooled OLS estimates with provincial and time-fixed effects. The sample considers all non-producing regencies near the land border where the sharing policy ends, on both sides. The columns indicate the regency's centroid geographical distance from the nearest relevant border. The baseline regression does not distinguish between borders, whereas the second and fourth columns introduce land border heterogeneity effects where the reference category is Java. Reported standard errors are clustered at the regency level.

Summary in English

Sustainable development—which is development that meets the needs of the present without compromising the ability of future generation to meet their own needs (Brundtland 1987, p. 54)—has become a critical, societally-pressing, and academically-en-vogue topic. Ever since the publication of the seminal report *The Limits to Growth* by the Club of Rome (Meadows et al. 1972), there are growing concerns that the patterns of economic activity experienced throughout the world cannot be maintained without damaging the future. Excessive economic activity is thought to be responsible for resource depletion and environmental degradation, saddling future generations with a less habitable planet. At the same time, current generations rely on economic activity to meet their own needs. Until recently, mainstream economics has focused mainly on the short-term ramifications of our economic actions. However, the growing concerns surrounding sustainable development have helped ignite a literature that considers how today's actions impact the ability of current and future generations to meet their needs. This dissertation contributes to this literature on sustainable development, examining on how natural resources are exploited to meet the needs of both current and future generations.

This dissertation comprises four empirical analyses that build on the theory known as the *capital approach* (Pearce and Atkinson 1993). This idea posits that sustainable development is achieved when future generations are bestowed with the capacity to be at least as well off as current generations. Current generations can influence this future capacity through the resources we bequeath. The more resources we transfer to future generations, the better they can pursue their own needs. This stock of resources is called *inclusive wealth* and comprises all capital assets that contribute to well-being. Inclusive wealth includes natural capital (i.e., natural resources supplied by the earth), produced capital (i.e., manufactured objects), and human capital (i.e., the productive abilities of humans). Hence, sustainable development is the net growth of inclusive wealth.

However, how can natural capital, which is a component of inclusive wealth, lead to its growth? Hartwick (1977) proposes that the revenues from resource extraction need to be sufficiently reinvested into human, natural, and produced capital assets to make a net gain in inclusive wealth. I call this *natural resource conversion*. It is the key to reconciling sustainable development (the needs of

the future) with the ills of resource depletion to meet the needs of the present. Although this idea has been well-known for decades, empirical investigations of Hartwick's proposition have been lacking. This dissertation addresses this gap by studying the phenomenon of natural resource conversion for sustainable development in four empirical studies.

My research provides various novel insights. (i) Natural resource-rich countries have the least sustainable development trajectories. These economies are currently at the center of the cross-country inclusive wealth distribution but are moving closer to the low-wealth group. Consequently, the development paths of rich and resource-rich nations are drifting apart. Although average incomes have risen disproportionately in resource-rich countries, this temporary gain in standards of living seems to come at the expense of their future generations.

This pattern is suggestive but not definitive proof of inadequate natural resource conversion by resource-rich nations. (ii) Natural resource depletion increases the rate of sustainable development, which can also mean they become less negative. Developing and resource-rich countries can spend natural resources revenues well because the investment opportunities in human- and produced capital have a highly beneficial societal impact. These capital types are scarce in these countries, meaning there is low-hanging fruit for schooling and infrastructure investments to be reaped. This thesis, therefore, tells two tales about resource-rich countries. On the one hand, they are blessed with better opportunities to spend their natural resource revenues. On the other hand, they suffer from an economic disadvantage due to an initial scarcity of human capital. (iii) Conversely, developed countries are abundant in human capital, which is the most vital driver of rates of inclusive wealth growth. Therefore, they do not need to rely on natural resource conversion for sustainable development.

Further conclusions are that (iv) the inhibitors of successful natural resource conversion are political resource curses, natural resource exports, and inadequate taxation of natural resource revenues. The process of natural resource conversion consists of four distinct phases: (1) discovery, (2) extraction, (3) appropriating revenues, and (4) allocating between public consumption and investments. This dissertation has shown that how countries organize these stages can explain significant cross-country heterogeneity. For instance, when institutions are weak, government corruption, private rent-seeking, patronage, and other opportunistic behaviors during the extraction stage create significant losses. Similarly, most countries that export natural resources are vulnerable to resource price fluctuations and a deterioration of their domestic economy. These curses hamper the use of natural resources for sustainable development.

Although (v) governments typically invest an adequate share of their collected resource revenues, collected via taxes, royalties, and fees sustainably, these are insufficient to mitigate the damage done earlier in the process. A case study in Indonesia finds a strong causal effect of resource windfalls on sustainable investments by local governments. Hence, this thesis suggests it is not a general apathy towards sustainable development that creates policy failure, but instead, deeply rooted institutional and economic factors.

Nederlandse samenvatting

Duurzame ontwikkeling—ontwikkeling die voorziet in de behoeften van het heden zonder het vermogen van toekomstige generaties om in hun eigen behoeften te voorzien in gevaar te brengen (Brundtland 1987, p.54) —is een bijzonder belangrijk, maatschappelijk-urgent, en academisch-en-vogue onderwerp. Sinds de publicatie van het baanbrekende rapport *The Limits to Growth* van de Club van Rome (Meadows et al. 1972), is er een groeiende bezorgdheid dat de wereldwijde economische activiteit niet kan worden gehandhaafd zonder de toekomst te schaden. Excessieve economische activiteit wordt verantwoordelijk geacht voor de uitputting van hulpbronnen en schade aan het milieu, waardoor toekomstige generaties worden opgezadeld met een minder bewoonbare planeet. Tegelijkertijd zijn huidige generaties afhankelijk van economische activiteit om in hun eigen behoeften te voorzien. Tot voor kort richtte de mainstream economische wetenschap zich vooral op de korte termijneffecten van onze economische acties. De groeiende bezorgdheid over duurzame ontwikkeling heeft echter geholpen een literatuur op te starten die onderzoekt hoe de acties van vandaag van invloed zijn op het vermogen van huidige én toekomstige generaties om in hun behoeften te voorzien. Dit proefschrift draagt bij aan deze literatuur over duurzame ontwikkeling. Het onderzoekt hoe natuurlijke hulpbronnen worden gebruikt om tegemoet te komen aan de behoeften van zowel huidige als toekomstige generaties.

Dit proefschrift bestaat uit vier empirische analyses die voortbouwen op de zogenaamde *kapitaalbenadering* (Pearce en Atkinson 1993). Deze theorie stelt dat duurzame ontwikkeling wordt bereikt wanneer toekomstige generaties de capaciteit erven om minstens zo welvarend te zijn als de huidige generaties. Het heden kan deze toekomstige capaciteit beïnvloeden via de middelen die wij nalaten. Hoe meer middelen wij aan toekomstige generaties overdragen, hoe beter zij in hun behoeften kunnen voorzien. Deze voorraad hulpbronnen wordt *inclusive wealth* genoemd en omvat alle kapitaalgoederen die bijdragen aan welzijn. *Inclusive wealth* omvat natuurlijk kapitaal (natuurlijke hulpbronnen), geproduceerd kapitaal (door de mens gemaakte objecten) en menselijk kapitaal (de vaardigheden van de mens). Duurzame ontwikkeling is dus een netto groei van *inclusive wealth*.

Maar hoe kan natuurlijk kapitaal, dat een onderdeel is van *inclusive wealth*, leiden tot de groei ervan? Hartwick (1977) stelt dat de inkomsten uit de winning van natuurlijke hulpbronnen voldoende moeten worden geherinvesteerd in menselijk en geproduceerd kapitaal zodat er een nettowinst aan *inclusive wealth* ontstaat. Ik noem dit fenomeen *de conversie van natuurlijke hulpbronnen*. Het is de sleutel tot het verzoenen van duurzame ontwikkeling (de behoeften van de toekomst) met de kwalen van het uitputten van hulpbronnen ter bevrediging van huidige behoeften. Hoewel dit idee al decennialang bekend is, zijn empirische onderzoeken naar *natuurlijke hulpbron conversie* afwezig. Dit proefschrift voorziet in deze leemte door het fenomeen in vier empirische studies te onderzoeken.

Mijn onderzoek levert verschillende nieuwe inzichten op. (i) Landen die rijk zijn aan natuurlijke hulpbronnen hebben de minst duurzame ontwikkelingstrajecten. Deze economieën hebben momenteel een ongeveer gemiddelde hoeveelheid *inclusive wealth*, maar komen steeds dichter in de buurt van de groep met een laag *inclusive wealth* niveau. De capaciteiten om welzijn na te streven tussen ontwikkelde landen en grondstofrijke landen groeien uit elkaar. Ondanks dat grondstofrijke landen hun gemiddeld inkomens fors hebben zien stijgen, is het vermogen van hun toekomstige generaties juist relatief verslechterd ten opzichte van de rest van de wereld.

Dit patroon is consistent, maar geen definitief bewijs voor omzetting van natuurlijke hulpbronnen conversie in landen die rijk zijn aan natuurlijke hulpbronnen. (ii) De uitputting van natuurlijke hulpbronnen verhoogt het tempo van duurzame ontwikkeling, wat ook kan betekenen dat ze minder negatief worden. Ontwikkelingslanden en landen die rijk zijn aan natuurlijke hulpbronnen kunnen inkomsten uit natuurlijke hulpbronnen goed besteden omdat er rijke investeringsmogelijkheden in menselijk en geproduceerd kapitaal bestaan in deze landen. Landen die rijk zijn aan natuurlijke hulpbronnen profiteren dus van een betere potentiële conversie van natuurlijk kapitaal. Tegelijkertijd hebben zij het nadeel nog schaars in menselijk kapitaal te zijn. (iii) Menselijk kapitaal is namelijk de belangrijkste bron van duurzame ontwikkeling. Ontwikkelde landen hebben menselijk kapitaal in overvloed en hoeven daarom niet meer te leunen op de conversie van natuurlijk kapitaal. Immers converteren rijke landen natuurlijke hulpbronnen minder efficiënt.

Daarnaast belicht mijn onderzoek de factoren die de conversie van natuurlijk kapitaal belemmeren. (iv) Struikelblokken voor succesvolle conversie zijn *politieke obstakels*, *de export van natuurlijke hulpbronnen*, en *ontoereikende grondstofbelastingen*. Het proefschrift ontleedt het proces van natuurlijk kapitaal conversie, het bestaat uit vier fasen: (1) ontdekking, (2) winning,

(3) toe-eigening van inkomsten, en (4) besteding en investeringen. Uit mijn onderzoek blijkt dat de manier waarop landen deze fasen organiseren leidt tot significante heterogeniteit tussen landen. Wanneer bijvoorbeeld de instituties (formele regels van een maatschappij) zwak zijn, zorgen overheidscorruptie en particulier winstbejag (rent-seeking) tijdens de extractie fase voor aanzienlijke verliezen. Evenzo zijn de meeste landen die hulpbronnen exporteren kwetsbaar voor schommelingen in grondstofprijzen en een verloedering van de nationale economie. Deze vloeken zorgen ervoor dat natuurlijke hulpbron exploitatie minder bijdraagt aan duurzame ontwikkeling.

Hoewel (v) uit mijn casestudy van Indonesië blijkt dat overheden doorgaans een adequaat deel van hun inkomsten duurzaam investeren, zijn deze onvoldoende om de schade die eerder is aangericht te mitigeren. Mijn thesis suggereert dat falend beleid niet komt vanuit een apathie of aversie ten opzichte van duurzame ontwikkeling, maar dat deze hun oorsprong kennen in systematische institutionele en economische factoren.

Research data management

The significance of data management in maintaining scientific work quality has grown considerably. Consequently, Radboud University has established stringent criteria for researchers to preserve scientific data and facilitate replication of their studies. In this section, the measures implemented to uphold data quality in our research are outlined. This thesis utilizes secondary data from a range of sources such as World Development Indicators, United Nation's Inclusive Wealth report, Indonesian Ministry of Finance, Indonesian Statistics Bureau (BPS), and United Nations University, among others. The datasets, along with syntax files (.do format), are saved in Radboud University's workgroup folders. Additionally, the data is stored at multiple offline sites (e.g., hard drives). The statistical software Stata is employed for data cleaning, analysis, and reporting. Moreover, a do-file is provided for each empirical chapter, detailing the modifications and empirical analyses. The data management practices in this dissertation adhere to the regulations and guidelines set forth by Radboud University.

Author contributions

Chapter 1:
Conceptualization: van Krevel
Investigation: van Krevel
Data curation: van Krevel
Writing – Original draft: van Krevel
Writing – Review and editing: van Krevel, van Hoorn, and Sent

Chapter 2:
Conceptualization: van Krevel
Methodology: van Krevel
Formal analysis: van Krevel
Investigation: van Krevel
Data curation: van Krevel
Writing – Original draft: van Krevel
Writing – Review and editing: van Krevel, van Hoorn, and Sent

Chapter 3:
Conceptualization: van Krevel
Methodology: van Krevel
Formal analysis: van Krevel
Investigation: van Krevel
Data curation: van Krevel
Writing – Original draft: van Krevel
Writing – Review and editing: van Krevel, van Hoorn, and Sent

Chapter 4:
Conceptualization: van Krevel and Peters
Methodology: van Krevel
Formal analysis: van Krevel
Investigation: van Krevel
Data curation: van Krevel
Writing – Original draft: van Krevel and Peters
Writing – Review and editing: van Krevel, van Hoorn, and Sent

Chapter 5:
Conceptualization: van Krevel
Methodology: van Krevel
Formal analysis: van Krevel
Investigation: van Krevel
Data curation: van Krevel
Writing – Original draft: van Krevel
Writing – Review and editing: van Krevel, van Hoorn, and Sent

Chapter 6:
Conceptualization: van Krevel
Writing – Original draft: van Krevel
Writing – Review and editing: van Krevel, van Hoorn, and Sent

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[1]. Well.. maybe I put in most of the work.

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Curriculum vitae

Charan was born on September 28th, 1990, in Nijmegen (The Netherlands). Charan completed high school (gymnasium) at Dominicus College in 2008 and started a bachelor's in economics at Radboud University and completed two specializations: International Economics and Financial Economics. Continuing a master's study in International Economics and Policy at Radboud, Charan graduated cum laude (8.9 of 10 GPA) in 2014. Charan subsequently worked as a lecturer at the department of Economics and Business Economics before starting as a lecturer and Ph.D. candidate for the same department.

Charan has been an integral part of the Nijmegen School of Management and its Ph.D. community. Serving as the chair for the Ph.D. council for two years, the Ph.D. representative in the Scientific Advisory Committee, and an elected representative in the Work's Council. During this time as a Ph.D. Candidate, Charan was awarded the 'Ph.D. Candidate of the Year' award twice for various involvements and achievements, once in 2020 and again in 2021 as part of the Ph.D. Council at the faculty.

Some of Charan's work has been published in peer-reviewed international journals already. Chapter 3 of this thesis has been published in the journal Resources Policy in 2021. Chapter 2 has been published in Social Indicators Research in 2023. Besides the academic endeavors, Charan has also been an active voice in public debates, appearing regularly in the media, giving public addresses, and consulting for public officials. Since completing the Ph.D., Charan works as Lecturer in Macroeconomics and International Economics at the Amsterdam School of Economics, University of Amsterdam.

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