Fair, Equitable, Efficient, and Just Sharing Royalties from Deep-Seabed Mining: Report to the Finance Committee of the International Seabed Authority

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Fair, Equitable, Efficient, and Just Sharing Royalties from Deep-Seabed Mining: Report to the Finance Committee of the International Seabed Authority

1. Introduction

This study updates ISA *Technical Study* 31 on equitable sharing of deep-seabed mining royalties. *Technical Study* 31 and this report build upon a report of the Secretary-General of the United Nations, issued in 1971 for the Committee on the Peaceful Uses of the Seabed and the Ocean Floor beyond the Limits of National Jurisdiction, on the possible methods and criteria for the sharing by the international community of proceeds and other benefits derived from the exploitation of the resources of the Area beyond the limits of national jurisdiction.[1] [2] [3]

As with *Technical Study* 31, this study sets out alternative cardinal, fair, equitable, efficient, and just sharing rules for royalties from deep-seabed mining using different ethical principles and formulae that balance individual and State interests, including equal division among States and Aristotle's Equity Principle. It demonstrates that evaluating estimated shares for distributive justice using alternative relative inequality metrics provides a superior formula that also maximizes social welfare.

The key differences from *Technical Study* 31 include the following. First, equitable intra-generational sharing formulae use updated World Bank and United Nations Statistics Division data (2021-2023 for ISA States Parties per capita Gross National Income hereafter denoted GNI_i and population) and 1980-2023 UN Scale of Assessment data to estimate the progressivity parameter from the annual United Nations General Assembly budget assessments. All values are in US$2023 now using the International Monetary Fund Special Drawing Rights Deflator rather than the United States Implicit Price Deflator for

[1] United Nations, "Possible Methods and Criteria for the Sharing by the International Community of Proceeds and Other Benefits Derived from the Exploitation of the Resources of the Area Beyond the Limits of National Jurisdiction", United Nations General Assembly, Committee on the Peaceful Uses of the Sea-bed and the Ocean Floor Beyond the Limits of National Jurisdiction, A/AC.138/38 and A/AC.138/38/Corr.1., mimeo, 1971.
[2] The 1971 report addressed the development of equitable sharing criteria and was aimed at providing the basis for a conceptual approach. It included the following list of non-financial benefits: expansion of world mineral resources, orderly development of resources, protection of the marine environment, enlarging the number of nationals with seabed technical competence, increasing the knowledge of the marine environment and seabed area, stability of raw material markets and preferential access to raw material for less developed countries. Financial benefits, on the other hand, were found to consist of the balance remaining after deduction of the expenditure from the revenues of the international machinery to be established (personnel, supplies, training, research, etc.). The report also contained a list of alternative criteria for the distribution of benefits, which were classified into two categories: direct distribution to governments, and allocation to programs of particular interest to developing countries. According to the report, before net proceeds reached a sufficiently large volume, direct distribution to all governments might lead to a fragmentation of financial resources, which would result in benefits of modest significance to the receiving countries.
[3] There is now an extensive literature on equitable sharing of deep-seabed mining royalties, including critiques of Technical Study 31, but none of this literature adds technical substance requiring response.

Gross Domestic Product. The IMF deflator captures a more comprehensive global deflation than the US deflator that measures US deflation.

Second, following the prominent international lawyer Rüdiger Wulfrum (1983, pp. 321-323), the sharing rule formulae introduce an interpretation of the Common Heritage of Humankind (hereafter denoted CHH) and United Nations Law of the Sea (hereafter denoted UNCLOS)-mandated equity in distribution (especially to developing States) based upon *de facto* equal participation. That is, all States have the right to exploit the deep-seabed minerals as the CHH but cannot due to circumstances beyond their responsibility or control. They receive compensation for this inequality of opportunity to participate in deep-seabed mining.

Traditionally, UNCLOS-mandated equity prioritizes equality of outcome in which all States ideally have equality in per capita Gross National Income (hereafter GNI_i), royalty share distribution, or other outcomes. But outcome differences can stem from both (1) inequality of opportunity due to circumstances over which people have no control and cannot be held responsible and (2) for reasons over which people have responsibility and control, such as choices over education, amount to work, preferences over leisure, etc.[4] This line of reasoning, a fairness concept, then compensates people for unfair inequality of opportunity while letting them enjoy the fair rewards for their responsibility, choices, and effort.

Thus, besides developing equity as preferential treatment to give equality of outcome, equity in distribution (following Wulfrum 1983) will also be developed as compensation to developing countries for inequality of opportunity to equally participate in deep-seabed mining due to factors beyond their responsibility or control (unfair inequality) while allowing for rewards to effort and responsibility (fair inequality). This redistribution framework differentiates between factors over which humankind and States can be held responsible and those for which they should not be held responsible. This 'responsibility-sensitive egalitarianism' (as it is called) has a long and rich history emanating in philosophy and subsequently operationalized by economics as developed below. Along with equality of outcome and opportunity, a third notion of equity will be developed as relative inequality aversion in distribution of income and royalty shares among individual ISA States Parties.

Third, conceptually rigorous definitions of efficiency, fairness, equity, and justice from philosophy and economics (which typically makes philosophical concepts mathematically rigorous, more nuanced, empirical, and operational), are also introduced. 'Equitable sharing' is expanded to become the more comprehensive 'fair, equitable, efficient, and just' sharing. Efficiency is inherent to sharing rules as developed below.

[4] Inequality of opportunity discussion drawn from the literature surveys of Roemer and Trannoy (2015) and Ferreira and Peragine (2016). See also Fleurbaey (2008). The inequality of opportunity discussion stems from Rawls (1971), Dworkin (1981ab), Sen (1985), Arneson (1989), and Cohen (1989). It is called responsibility-sensitive egalitarianism (Cohen 1989) and quipped as luck egalitarianism (Anderson 1999).

Fourth, the UN Multidimensional Vulnerability Index is included as a variable in the sharing rules. This variable accounts for inequality of opportunity due to chronic structural challenges that are becoming more interconnected and intense over time (UN 2024). States with high vulnerability, such as the Small Island Developing States, may not have the GNI_i but they face greater costs. Traditional measures of development insufficiently capture their vulnerabilities. For example, GNI_i measures the income of a country but that does not inform how much it costs to handle major threats like catastrophic sudden weather events or the cost of servicing old debts.

Fifth, intra-generational sharing will be developed as part of a more comprehensive and integrated framework for both intra- and inter-generational sharing compliant with the CHH and UNCLOS. Optimizing the fair, equitable, efficient, and just net benefits for 'Humankind' within and across generations from mining and its twin of conservation of biodiversity and ecosystem services can be developed as sustainable development Dasgupta (2021) with the aid of the existing ISA 3.75% social discount rate (Freeman et al. 2020). Allowing for a possible global interpretation of CHH, deep-seabed mining and intra- and inter-generational sharing are extended to include spillover impacts on terrestrial mining (and its environmental and social external costs) and climate change mitigation as the global energy system transitions from fossil-fuel to critical-mineral basis.

A few caveats. ISA decision-making on the intra- and inter-generational distribution of royalties and the nature of sharing rules are distinct from mining decisions. Hence, sharing rules do not impact mining incentives and decisions. The sharing rules are also independent of the royalty payment regime, contractor regulations, and any impacts upon terrestrial mining prices.

The following discussion pertains to Article 140 distributions with the exception of Article 82 distributions discussed in Section 17.

Readers interested in the main results can read 'Section 2. Executive Summary'. Remaining with a summary and overview, readers interested in somewhat more empirical detail can read, 'Section 15. Intra-Generational Sharing Empirical Results: Summary'.

2. Executive Summary

2.1. The CHH, a principle of international law and ethics, is operationalized by defining Humankind as '*legal cosmopolitan individuals of current and future generations that reside in ISA States Parties regardless of citizenship'*, called cosmopolitans for short.

2.2. Three concepts of equity are pertinent: relative inequality aversion to outcomes, inequality of opportunity (also a fairness concept), and inter-generational.

2.3. Efficiency in distributed royalty is Pareto-efficiency. Increasing one States Party's share requires reducing another's.

2.4. Fairness appeals to some idea of equitable and impartial treatment of States Parties and cosmopolitans in the ISA. Fairness in this report includes non-envy[5], (in)equality of opportunity (also an equity concept), and fair bargains (decisions are jointly, collaboratively, directly, and unanimously decided by sovereign States themselves, not by a third party). Fair bargains impart impartiality and recommendations an 'impartial arbitrator/spectator' or impartial judge (*Nyayadish* as arbiter of truth) would make (i.e., without personal stake).

2.5. This report broadly defines justice as fair, equitable, and impartial treatment of all individuals under the law or within an organization (Miller 1999, 2023). This report's scope of justice is pluralist (multiple concepts of justice apply). The combined procedural and distributive justice implied by ISA decision-making is pluralist, local (how institutions not society divide), positive (justice as a 'political value' rather than normative deriving from a comprehensive moral system), fair (non-envy, fair bargains, and equality of opportunity), impartial (imparted by fair bargains), not Sanskrit's *Niti* (just institutions and society) but *Nyaya* (their realization), commutative (fair voluntary exchange between parities, here treating parties equally under international law), international for States Parties, internationalist pluralist for cosmopolitans represented by States Parties (hybrid of international for States Parties and global for cosmopolitans on their own), legal, and legitimate.

2.6. Following Wulfrum's (1983, pp. 321-322) interpretation of CHH, UNCLOS-mandated equity in distribution is compensation for inequality of opportunity to participate in deep-seabed mining. This responsibility-sensitive egalitarianism is implemented using distribution weights that redistribute royalties from States Parties with above-average GNI_i to below-average GNI_i. Distributed royalties create participation 'affirmative action' to ensure cosmopolitan owners enjoy Wulfrum's equality of opportunity. (The Enterprise also addresses inequality of opportunity.) Distributed royalties address the inequality of opportunity that is a major way inequality is transmitted between generations.

2.7. Distribution weights inherently incorporate one of this report's definition of equity, relative inequality aversion to inequality in income distribution and royalty share distribution. Distribution weights, by redistributing royalty shares from higher-income to lower-income States Parties, also indirectly implement Wulfrum's (1983, pp. 321-323) second interpretation of the CHH principle as preferential treatment for developing countries to foster economic development.

2.8. Three distribution weights implement compensation for inequality of opportunity and one implements equality of outcome in GNI_i. As noted, distribution weights redistribute

[5] No individual should strictly prefer any other portion of the distribution to its own (Foley 1967, Varian 1974).

royalty shares from higher-income to lower-income States Parties. Some version of ISA overall mean GNI_i serves as the norm or benchmark for higher and lower income.

2.9. Under the CHH, Humankind's (cosmopolitans') ownership of the Area and its resources establishes a claim and entitlement[6] to royalties based upon proportionality, thereby supporting a proportional sharing rule. UNCLOS-mandated equity in distribution prioritizes developing States Parties, here implemented through GNI_i larger or smaller than the overall grand mean for all ISA and distribution weights accounting for either inequality of opportunity or equality of outcome. ISA States Parties (through primary legal subjectivity, international legal personality, standing, and legal capacity) necessarily represent cosmopolitans. Juridical parity establishes equal division rules for States Parties (and fairness as non-envy). The tension between cosmopolitan weighted proportionality sharing and States Parties equal division sharing is resolved through geometric mean functional form sharing rules and evaluating distributed royalty shares among States Parties for equality of outcome and global social welfare (using standard equity metrics).

2.10. Intra-generational sharing rules for royalties to individual States Parties are a multiplicative (multiplied together) function of the variables: population share, MVI, and distribution weight. Sharing rule functional form can be with or without geometric mean (which raises each of the three variables by the exponent $\frac{1}{3}$). Desert[7], poverty alleviation[8], merit[9], need[10], and compensation for past injustice (corrective justice) can constitute rationales for allocation rules but none of these rationales satisfy Articles 82 or 140, and hence are excluded.

2.11. Empirical results for distributed royalty shares for intra-generational equality of outcome and global social welfare among States Parties show that: (1) geometric mean sharing rules are preferred, (2) sharing rules using distribution weights incorporating inequality of opportunity rather than equality of outcome are preferred, (3) geometric mean sharing rules incorporating inequality of opportunity give identical or very close equality outcome and global social welfare, (4) the recommended (for various practical reasons) geometric mean sharing rule uses the distribution weight unfair GNI_i / mean observed GNI_i.

2.12. Section 15 below provides more comprehensive summary of the empirical results and Section 16 provides full details.

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[6] Positive concept. Relies upon rules, laws, contracts, and other similar institutions, entitling an individual to something from another individual on some basis (Feldman and Skow 2020).

[7] Normative, contextual concept that some individual deserves some benefit due to an activity or performance (desert base) (Miller 1999).

[8] Reduce poverty gap or rate (Saez and Stantcheva 2016).

[9] Normative, contextual concept related to quality, worth (Mulligan 2023).

[10] Normative, contextual concept based upon some general standard to which parties are entitled (Miller 1999, Kanow 2003)

2.13. Section 17 discusses Article 82 distributions.

2.14. Sustainable development balances economic, social, and environmental needs to ensure and balance the well-being of current and future generations through inclusive wealth and balancing of natural, produced, and human capital. Sustainable development integrates intra- and inter-generational equity (the latter includes the Sustainability Fund). Dasgupta's (2021) sustainable development framework and the current ISA discount rate of 3.75% (Freeman et al. 2020) are recommended as ways to implement inter-generational equity and sharing.

2.15. Should the CHH principle be interpreted as accounting for humankind in general throughout the globe and not simply confined to the Area and mining, then the sustainable development framework can be extended to account for spillover impacts onto terrestrial mining (including environmental and social costs), and balancing the marginal economic contributions of deep-seabed and terrestrial mining, recycling and reuse, and mineral supply impacting climate change.[11]

2.16. Whether sustainable development alone or any extension of the CHH principle to a global egalitarian framework (simultaneously considering terrestrial mining, recycling and reuse, and climate change) is only qualitative. Many of the external environmental and social external costs involved in mining both the terrestrial and deep-sea environments are damages to natural capital that are difficult to quantitatively value.

2.17. Pervasive risk and especially uncertainty pose perhaps the most significant challenge for optimal policy even greater than external cost valuation. One of the greatest sources of uncertainty is discontinuous costs generated by potential irreversible environmental impacts, most notably extinction in both terrestrial and deep-seabed mining and indirectly through climate change.

3. Common Heritage of Humankind

The CHH, a principle of international law and ethics, is made operational in the following ways.[12] Humankind is defined as '*legal cosmopolitan individuals of current and future generations that reside in ISA States Parties countries regardless of citizenship'*, called cosmopolitans for short. Cosmopolitans in sharing rules are represented by the population share of an individual ISA States Party among all ISA States Parties.

[11] In principle, addressing deep-seabed mining technological externalities (spillovers) upon terrestrial mining and climate is comparable to UNCLOS-mandated addressing adverse deep-seabed mining impacts upon prices received for terrestrial mining (called a pecuniary externality that works through prices and distribution).

[12] See Wulfrum (1983), Lodge (2012), Noyes (2012), and Shackleford (2009) for CHH discussions.

'Humankind' as cosmopolitans is not a primary subject with international legal personality under public international law or within the ISA.[13] Instead, at a minimum and by consent and action of States through the ISA, these cosmopolitans become an object or derived subject, granted derived international legal personality (in relation to the States creating it). Cosmopolitans' international personality is confined to the rights, obligations, and duties conferred by the ISA States Parties and do not stretch to other areas of public international law. Cosmopolitans, as derived international legal persons, then possess limited secondary legal rights, capacity, and standing (*ius standi*), but nonetheless enforceable claims for Area royalties and other benefits in the ISA.

Cosmopolitans are the collective owners of the Area and its resources. The law and economics classification of the Area and its resources is regulated common property with the ISA providing stewardship and management.[14] The cosmopolitan claim on and entitlement to Area resources and benefits are based upon this Area ownership. Current generation cosmopolitans necessarily represent future generations, and both are represented in the ISA by States Parties who have primary subjectivity, international legal personality, legal capacity, and standing.

4. UNCLOS-Mandated Equity in Distribution as Compensation for Inequality of Opportunity to Participate in Mining

UNCLOS-mandated equity in distribution in this report follows Wulfrum's (1983) development of the CHH principle.

Two schools of thought consider why and how the deep-seabed regime based on the CHH should equitably distribute royalties to account for developing States: *de facto* equal participation and preferential treatment (Wulfrum 1983, pp. 321-323).[15] The first school (*de facto* equal participation) recognizes that all States have the right to exploit the deep-seabed minerals, and the resulting benefits are to be enjoyed by all Humankind (i.e., cosmopolitans) who collectively own the Area and its resources. In the words of Wolfrum (1983, p. 321), "Thus, the receipt of revenues was to be regarded as a form of indirect participation in deep seabed-bed mining or, in other words a sort of compensation which – as all States enjoyed equal rights with respect to the seabed -- constituted the right of the respective non-mining States."

This first school of thought is compensation for Area owner cosmopolitans' (i.e., humankind without ISA primary international legal personality or standing) and their representing States Parties' (with international legal personality and standing) inequality of opportunity to participate in deep-seabed mining due to circumstances (opportunities)

[13] Discussion based upon Orakhelashvili (2001), Peters (2016), and Brölmann and Nijman (2017).
[14] See Baland and Platteau (1996).
[15] Wulfrum (1983, p. 321) states, "The second justification for the obligation to provide for revenue sharing was seen in the demand that resources from the sea-bed should be used to foster the economic development of the developing countries – the original preferential treatment."

beyond their control or responsibility.[16] Cosmopolitans and the States Parties representing them enjoy natural (liberal) rewards for differences in outcomes over which these cosmopolitans are responsible for and over which they have control and exert effort.

In this responsibility-sensitive egalitarian view, justice does not require equality of individuals' final outcomes or achievements (equality of outcome), which here is actual mining (although the Enterprise can achieve this). Instead, once the means or opportunities to reach a desired outcome have been equally distributed (here royalty shares, recognizing that the Enterprise ensures direct participation), which opportunity from those open to the individual and that the individual chooses lies outside the scope of justice.

The sharing rules use distribution weights in the royalty sharing rules to implement this UNCLOS-mandated equity in distribution (as compensation for inequality of opportunity to participate in deep-seabed mining for circumstances beyond cosmopolitans' responsibility or control) while still allowing natural rewards for effort. By using distribution weights, distributed royalties create participation 'affirmative action' to ensure cosmopolitan owners enjoy *de facto* equality of opportunity. Distributed royalties also address the inequality of opportunity that is a way inequality is transmitted between generations.

Distribution weights also inherently incorporate one of this report's definitions of equity, relative inequality aversion to inequality in income and royalty share distribution. Weights, by transferring royalty shares from higher income to lower-income States Parties, also indirectly implement Wulfrum's (1983, pp. 321-323) second interpretation of the CHH principle as preferential treatment for for developing countries to foster economic development.

5. Equity

Equity, a highly contested concept, refers to equality of some sort but is distinguished from strict equality (in sharing rules the term equal division is used). Multiple concepts of equity exist. Two concepts of equity are used. One is ISA States Parties relative inequality aversion to outcomes (i.e., how much States Parties dislike inequality in the distribution of resources, income, wealth, or policy impacts), here income and royalty shares. Second is Area owner cosmopolitans' inequality of opportunity to participate in deep-seabed mining (following Wulfrum 1983), which is also a fairness concept.

[16] Compensation for circumstances is called *ex-ante* and for responsibility or effort is called *ex-post* (Ferreira and Peragine 2016). Compensation in this report unless explicitly used for responsibility or effort (which is *ex-post* compensation) is always *ex-ante*. Fleurbaey (2008) discusses control versus preferences in the responsibility argument.

Throughout this report, two ***equalisandum*** apply. The first is a States Party's GNI_i as a way to operationalize equity in royalty share distribution. The second is royalty share distribution itself.

The third notion of equity used is inter-generational. Inter-generational equity, a principle of fairness and justice between generations, ensures that current generations meet their needs without compromising that of future generations. It is a core concept of sustainable development and raises the question of how future generations exercise their ownership right and associated royalty (and other benefits) claim (Lodge et al. 2017). The answer is through current generations of cosmopolitans (through their representing States Parties) either: (1) leaving an equitable share of the resource *in situ* for future generations' extraction or (2) or saving and investing current extraction royalties to increase future generations' consumption by reducing current consumption. There is thus a trade-off between current and future consumption. This inter-generational equity, implemented through sustainable development, is discussed below.

6. Fairness

Multiple definitions of fairness exist, depending upon context. In general, fairness focuses on the process and ensuring that rules are applied consistently. Fairness in this report appeals to some idea of equitable and impartial treatment of States Parties and cosmopolitans in the ISA. A clear source of ISA fairness is revealed by its decision-making process. Fairness in this report also ensures that 'Humankind' and States Parties have access to the resources and opportunities they need to succeed (here following Wulfrum (1983, pp. 321-323), equality of opportunity to participate in deep-seabed mining).

Definitions of fairness in this report include non-envy, (in)equality of opportunity (also an equity concept), fair bargains (decisions are jointly, collaboratively, directly, and unanimously decided by sovereign States themselves, not by a third party) leading to impartiality and recommendations an 'impartial arbitrator/spectator' or impartial judge (*Nyayadish* as arbiter of truth) would make (i.e., without personal stake).[17] Assume hereafter that fairness before and after distribution remain unchanged, i.e., fairness is time consistent.

7. Scope of Justice

The report's scope of justice is pluralist, meaning that multiple concepts of justice apply. The combined procedural and distributive justice implied by ISA decision-making can be defined as pluralist, local (how institutions not society divide), positive (justice as a 'political value' rather than normative deriving from a comprehensive moral system and

[17] Mohism (Mozi) also advocates impartiality (Fraser 2023). Discussion draw from Elster (1992), Thomson (1994), Young (1994), Barry (1996), Miller (1999, 2023), Mariotti (1999), Dworkin (2000), Konow (2003), Caney (2005), Sen (2009), Risse (2012), and Fleurbaey (2019).

proceeding independent of metaphysics and epistemology), fair (fair bargains and equality of opportunity), impartial[18] (imparted by fair bargains), not Sanskrit's *Niti* (just institutions and society) but *Nyaya* (their realization), commutative (fair voluntary exchange between parities, here treating parties equally under international law), international for States Parties, internationalist pluralist for cosmopolitans represented by States Parties (hybrid of international for States Parties and global for cosmopolitans on their own), legal, and legitimate. The focus is not the ISA as 'just institutions' (Rawls 1971) or 'just society' (Xunzi n.d.), but the nature of the ISA revealed ethical preferences and local justice.

8. Efficiency

All share distributions are Pareto-efficient, since redistribution from States Party to another requires the relinquishing States Party to reduce its share.

9. Shares Rather Than Royalties

Distributing shares instead of the actual royalties uses a stable and consistent formula that allows the actual distributed shares to rise and fall in concert with the total royalties to be distributed in each period of time.

10. Basis of Sharing: Claims, Priority, and Equity Principles

Cosmopolitans' claim on and entitlement to royalties stem from cosmopolitans' collective ownership of the Area, the Area's deep-seabed natural capital of minerals and environment, and resulting benefits. States Parties represent current and future generations of cosmopolitans' ownership royalty claims. Distribution of deep-seabed mining royalties to cosmopolitans through States Parties is thus a claims problem and equity principles apply.[19] Priority in distribution is based upon UNCLOS Articles 82 and 140. Desert, poverty, merit, need, and compensation for past injustice (Aristotle's corrective justice) can constitute rationales for allocation rules but none of these rationales satisfy Articles 82 or 140 or Wulfrum's (1983) CHH interpretation.

Which equity principles to apply depends in part upon the number and nature of the benefit, burden, 'good', or 'bad' distributed. Deep-seabed mining royalties are a single homogenous divisible private 'good' measured by a common metric, dollars, leading to

[18] Justice as impartiality separates justice from undue influences of self-interest, power, and coercion, emphasizing parties' voluntary acceptance of outcomes, and separates justice from undue influence (Albin 2001). What is considered just draws forth consent without use of threats or reward. This contractarian justice is what would be agreed upon by individuals placed in appropriately specified circumstances (Thomson 1994, Miller 1999) or an impartial spectator (Parfit 1997, Sen 2009). Distribution rules are impartially applied and selected.

[19] Equity principles refer to concepts or guidelines that focus on equity, fairness, and justice in the distribution of resources, opportunities, or treatment within a society or system. Claims problem: rationing problem where individuals have claims on resources that cannot all be satisfied (O'Neill 1982).

one equity principle underpinning sharing rules for cosmopolitans, Aristotle's Equity Principle of proportionality. A second equity principle underpinning sharing rules is equal treatment of equals and equal division of royalty shares for States Parties.

Equity principles differ when the distributed 'good' is lumpy and indivisible, often found with public goods or bads and more generally non-monetary benefits, e.g., technology or knowledge more broadly, capacity building, and training. Hence, one set of equity principles will be used for intra-generational equity and royalty sharing and another set (e.g., point systems but not discussed here) for inter-generational equity and royalty-financed public goods and inter-generational equity such as capacity building and training, deep-sea research, etc. and more broadly, sustainable development (discussed below).

Equity principles are used here as policy instruments or tools with normative content to structure and implement distribution of royalty shares accounting for the three fundamental objectives and features underlying distribution. The first stems from humankind's collective ownership of the Area's resources that establishes humankind's claim and entitlement to receive deep-seabed mining royalty shares and gives Aristotle's Equity Principle (2009, V:1130b-1132b) to proportionately distribute royalty shares to cosmopolitans based upon a States Party's population share of all humankind in the ISA States Parties.[20] The second equity principle is UNCLOS-mandated priority in distribution, i.e., equity in distribution especially for developing States, that is interpreted as compensation for humankind's inequality of opportunity to participate in deep-seabed mining (Wulfrum 1983). This prioritized intra-generational sharing of royalties is implemented through distribution weights that give weighted proportionality for cosmopolitans and implicitly transfer royalty shares from higher income to lower income States Parties. The third equity principle stems from ISA States Parties juridical parity and decision-making in the ISA that lead to the fundamental equity and fairness concept of equal treatment of equals and equity principle of equal division and equality of outcome for royalty shares among States Parties.

11. Balancing Cosmopolitan Area Ownership and Inequality of Opportunity with States Parties Parity and Strict Equality of Outcome

A major challenge for the proposed sharing rules is balancing cosmopolitan prioritized weighted proportional sharing (prioritized through equity adjustments for inequality of opportunity using distribution weights) with States Parties equal division of royalties and equality of outcome. One way these competing principles and equity concepts are balanced and reconciled is that sharing rules are specified using distribution weights to incorporate compensation for inequality of opportunity (which is deontic[21]). A second way is through the functional or mathematical form by which the sharing rules are specified

[20] Mohism (Mozi) also advocates proportionality (Fraser 2024).

[21] Deontologism is a normative ethical theory that focuses on the morality of actions themselves, rather than the consequences of those actions (as in consequentialism).

(sharing rules written as geometric means, also deontic). The third way is ranking distributed royalty sharing rules from highest to lowest equality of outcome (corresponding to equal division of royalties to States Parties) using standard equity metrics (Lorenz curve, Gini coefficient, and Atkinson and Generalized Entropy). (This third way is consequentialist.[22]) Most of these equity metrics do more than evaluate equality of outcome (equity as relative inequality aversion) but also allow ranking for social welfare from highest to lowest in the same order as the equality of outcome in allocation of royalty shares to individual States Parties.

12. Intra-Generational Sharing Rules[23]

Multiple sharing rules are developed using proportional sharing for States Parties' cosmopolitans measured by share of total population and including the UN Multidimensional Vulnerability Index. As noted, UCLOS-mandated equity in distribution, (interpreted as compensation for inequality of opportunity to participate in deep-seabed mining) is implemented through different types of distribution weights in turn corresponding to different specifications and interpretations of inequality of opportunity or outcome.

Two different sharing rule functional forms (algebraic formulae) are used to balance cosmopolitan ownership and under public international law States Parties' juridical parity, primary subjectivity, primary international legal personality, standing, and legal capacity in the ISA: multiplicative with and without geometric mean. (Multiplicative means the variables are multiplied together because they interact with each rather than are added together.) Geometric mean has superior mathematical properties over a multiplicative specification with an implicit exponent of one and has precedent (e.g., Human Development Index).

13. Distribution Weights to Implement Intra-Generational Equity in Distribution[24]

As noted, distribution weights in sharing rules implement compensation for inequality of opportunity to participate in mining by transferring royalty shares from higher income to lower income States Parties. ISA overall mean GNI_i serves as the norm or basis of comparison to establish higher- and-lower income States Parties and cosmopolitans.

[22] Consequentialism is a normative ethical theory judging actions based upon outcomes rather than procedure. Using equity metrics to evaluate distributed royalty shares for equality of outcome is consequentialist.

[23] Discussion drawn from Young (1994), Moulin (2003), Hoogaard (2009), and Thomson (2019).

[24] On distribution weights in general and especially for equality of outcome see Ray (1984), Squire and van der Tak (1999), Adler (2016), and Fleurbaey and Abi-Rafeh (2016). Average egalitarian equivalence (Moulin 2003, Fleurbaey 2008) is one preferred method to implement inequality of opportunity but insufficient observations preclude its implementation (which must be through a structural model rather than machine learning random forest predictions).

The way that distribution weights are constructed using mean GNI_i of all ISA States Parties as the norm or basis of comparison for how to measure equitable distribution (interpreted as relative inequality aversion) necessarily and implicitly incorporates inequality in income distribution into inequality of opportunity as the basis of UNCLOS-mandated equity in distribution. Moreover, use of overall ISA mean GNI_i as the equity (relative inequality aversion) norm and the inequality of opportunity compensation interpretation for UNCLOS-mandated equity in distribution necessarily implement preferential treatment for lower-income States Parties. Such treatment in turn implements Wulfrum's (1983) second interpretation of UNCLOS-mandated equity in distribution as preferential treatment for developing countries to foster economic development. Hence, three interpretations of 'equity in distribution' are implemented when compensating for inequality of opportunity to participate in deep-seabed mining: compensation for inequality of opportunity, relative inequality aversion (measured by GNI_i greater or lower than overall mean), and equality of outcome for royalty share distributions for individual States Parties (measured by equity metrics).

As noted, distribution weights use mean GNI_i as the norm or benchmark for whether GNI_i is unequal and the inequality of opportunity interpretation for equity indirectly implements preferential treatment for lower-income States Parties. Wulfurm's (1983) second interpretation of UNCLOS-mandated equity in distribution as preferential treatment.

13.1. Equality of Outcome Distribution Weight

The standard Equality of Outcome distribution weight is: $\omega_i(EO) = \left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$.[25] Progressivity parameter, η, corresponds to how the marginal value of a dollar declines with income. (Technically, η is the elasticity of social marginal utility from economics social welfare function. $0 \leq \eta \leq \infty$. The larger is η, the stronger is relative inequality aversion and progressivity in distributing income, benefits, and costs. $\eta = 0$ gives no inequality aversion (Utilitarianism), $\eta = 1$ corresponds to proportionality, and $\eta = \infty$ gives highest priority to the worst off (Rawls' difference principle, Rawls 1971). 'Pre-redistribution' overall mean GNI_i, $\overline{GNI} = \sum_{i=1}^{N} \frac{GNI_i}{N}$, benchmarks fair and unfair income. N denotes the total number of ISA States Parties (168, where the European Union is excluded). $\overline{GNI}$ is observed perfectly egalitarian ISA mean GNI_i, overlooking inequality of opportunity.

$\eta = 0.0001017$ is empirically estimated as UN General Assembly revealed ethical preferences from annual budget assessments (Appendix). $\eta = 0.0001017$ effectively implies Utilitarianism, whereby the ethical norm is maximizing the overall greatest good or utility without concern for the distributional impacts (here among States Parties or cosmopolitans). $\eta = 0.0001017$ due to UN decision making is fair and impartial. Fair revealed ethical preference η can serve as focal point for any ISA stated ethical preferences for η. As developed below, this report recommends that ISA adopts the stated

[25] $\omega_i(EO)$ is welfarist, i.e., based upon a social welfare function and utility.

preference value of $\eta = 1$ which corresponds to proportionality and for which there is considerable precedent (e.g., Stern's 2006 climate report).

13.2. Inequality of Outcome Distribution Weights

The inequality of opportunity distribution weight for *ex-ante* compensation with liberal rewards $\omega_i(\mathrm{IO}_p)$, is calculated with the same formula as $\omega_i(EO)$ but removes fair inequality (due to responsibility and effort) from GNI_i while preserving unfair inequality (due to inequality of opportunities and circumstances beyond cosmopolitans and States Parties control). $\widehat{GNI}_i$ is predicted unfair GNI_i from a machine learning algorithm (random forest) relating GNI_i to circumstance variables. The Appendix discusses the empirical estimation and Table 3 summarizes these variables.

The inequality of opportunity distribution weight $\omega_i(IO_p)$ compares unfair income $\widehat{GNI}_i$ to the overall grand mean of all observed income (including both fair and unfair GNI_i) $\overline{GNI} = \sum_{i=1}^{N} \frac{GNI_i}{N}$, benchmarks fair and unfair income. $\omega_i(IO_p) = \frac{\widehat{GNI}}{\overline{GNI}}$ redistributes royalty shares from less unfair (due to circumstances beyond their control) income to more unfair income cosmopolitans when $\frac{\widehat{GNI}}{\overline{GNI}} > 1$, i.e. $\overline{GNI} > \widehat{GNI}_i$. The more unfair is inequality of opportunity due to circumstances relative to $\overline{GNI}$, the larger is $\widehat{GNI}_i$ relative to $\overline{GNI}$ and the larger the *ex-ante* compensation with liberal rewards implemented by $\omega_i(IO_P)$.

Generalized Proportionality (Almås *et al.* 2011, Cappelen and Tungodden 2017) extends proportional allocation to more complex decision-making scenarios in which allocation is not just about a single basis for the claim but entails multiple criteria. It's about achieving fairness across a broader range of scenarios in resource allocation

The generalized proportionality principle allocating royalty shares gives each cosmopolitan's fair share it would receive in the hypothetical situation in which everyone has the same opportunities (circumstances) defined as the average of the pre-redistribution (before applying compensation transfers) GNI_i of all ISA cosmopolitans, and each cosmopolitan has its actual distribution of effort (responsibility factors) (Almås *et al.* 2011, Cappelen and Tungodden 2017). Hence, a cosmopolitan's claim depends on the circumstances (non-responsibility factors) of all cosmopolitans in the ISA, but only on the cosmopolitan's own effort (responsibility factors).

Unfortunately, average egalitarian royalty share distribution Fleurbaey 2008) cannot be implemented because estimating the distribution weights requires more complete data on all States Parties than are available.

Redistribution starts with equal CHH ownership claims and royalty shares for all ISA cosmopolitans. Generalized proportionality then aims to redistribute shares among cosmopolitans to neutralize unfair inequalities stemming from unequal opportunities

while respecting fair inequalities that arise from individual responsibility, choices, and effort. It is egalitarian because it eliminates all unfair inequalities arising from circumstances. The principle is responsibility-sensitive because it preserves fair inequalities and natural rewards that only arise from responsibility factors or effort.

The redistribution mechanism would assess cosmopolitans who's actual GNI_i exceed their hypothetical GNI_i under average opportunities. The redistribution mechanism transfers royalty shares to those who's GNI_i falls short due to inferior opportunities. The redistribution mechanism maintains proportionality to effort or choice within the equal-opportunity framework (starting from equal CHH ownership claims and royalties for each cosmopolitan).

The distribution weight for generalized proportionality is $\omega_{\mathrm{i}}\left(IO_p^{GP}\right) = \frac{\widehat{GNI}_i^R}{\sum_{i=1}^{N} \widehat{GNI}_i^R}$. N denotes the number of ISA States Parties (excluding the European Union). $\widehat{GNI}_i^R$ is predicted GNI_i estimated in the same way as $\widehat{GNI}_i$ using random forest modeling except that the regressors are responsibility rather than circumstance variables. Table 3 summarizes these variables.

14. Sharing Rules

This section develops fair division rules to equitably, fairly, efficiently, legally, and legitimately distribute royalty shares to Area cosmopolitan owners, represented by their States Parties, as a claims problem. Thus, entitlement to royalties is based upon the cosmopolitan ownership claim. The discussion develops only equal division and proportionality and their prioritized versions (priority implemented using social distribution weights) with and without geometric mean functional form.

Equal division divides losses equally among all claimants. It is an unambiguous and desirable rule when all parties are similarly situated. Equal division gives equal treatment of equals. Claimants are treated equally, either because they are considered equal under the circumstances or because there is no clear way to distinguish among them. This rule is envy-free since all claimants have equal claims. Equal division is generally not appropriate when claimants are not similarly situated. Equal Division (without priority) equally divides royalty shares among $N = 168$ States Parties i which when including the MVI_i gives:

$$S_i = \frac{MVI_i}{N}. \tag{1}$$

Proportionality, a long-standing equity principle tracing back to Aristotle (2009, V:1130b-1132b) in Western philosophy, also surfaces elsewhere (e.g., Chinese equal-field system allocating government land proportional to labor supplied, also adopted in Japan, Mei

1974).[26] Proportionality is well-suited for a private good/bad that is single, divisible, and homogeneous and cardinally measured by a common metric at the scale at which the decision is being made, here US$. Proportionality is thus well-suited for royalty shares. Proportionality acknowledges differences in magnitudes of parties' claims and divides outcomes in proportion to these differences. Due to its unique collusion-proof properties, proportionality is often a preferred equity principle. Any other distribution rule can potentially be manipulated by transferring claims across claimants or changing their identity by disaggregating/aggregating into smaller/larger coalitions.

Proportionality treats units of claim equally, rather than claimants that possess them. Proportionality thus equally weights each unit of claim, regardless of claimant. Proportionality equalizes the ratio between claims and awards. Proportionality satisfies fairness (Yaari and Bar- Hillel 1984).

Proportionality distributes royalties proportional to individual cosmopolitan claims, where each unit of claim is treated equally. Proportionality allocates shares to each individual cosmopolitan claimant according to the proportion of all individual cosmopolitans' claims. Here cosmopolitan entitlement to royalties is established from CHH cosmopolitan Area ownership measured by each States Party i's share (proportion) of the total ISA population, denoted P_i. The royalty share for States Party i without a distribution weight (and hence not accounting for UNCLOS-mandated equity-in-distribution) is:

$$S_i = \frac{P_i MVI_i}{\sum_{i=1}^{N} P_i MVI_i}. \quad (2)$$

Priority and weighted distribution arise when an equity principle (here equal division and proportionality) is differentiated by priority of certain claims. Weights are assigned to prioritize some claims over others according to claimants' characteristics. Weighted equal division is: $S_i = \omega_i \frac{1}{N}$, where ω_i denotes a generic distribution weight for equality of outcome or inequality of opportunity using distribution weight $\omega_i(EO) = \left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$ for equality of outcome and distribution weights using inequality of opportunity distribution weights $\omega_i(IO_p) = \frac{\widehat{GNI}_i}{\overline{\widehat{GNI}}}$, $\omega_i(IO_p^U) = \frac{\widehat{GNI}_i}{\overline{\widehat{GNI}}}$, or $\omega_i(IO_p^{GP}) = \frac{\widehat{GNI}_i^R}{\sum_{i=1}^{N} \widehat{GNI}_i^R}$ for generalized proportionality.

Weighted proportionality is:

$$S_i = \frac{P_i MVI_i \omega_i}{\sum_{i=1}^{N} P_i MVI_i \omega_i}. \quad (3)$$

[26] Non-Western philosophical thought typically does not frame 'proportionality' as a distinct Western-style principle but nonetheless permeates ethical and practical concepts.

Multiple variables X_j, such as multiple bases for claims (e.g., need, desert) beyond the Multidimensional Vulnerability Index (MVI_i) and population share P_i can be added to distribution rules although as noted are excluded here.

Aggregation and index number theory apply to S_i as an index (such as the Consumer Price Index) that aggregates individual variables (Blackorby *et al*. 1978). Cobb-Douglas aggregation gives multiplicative aggregation that exponentially weights each variable by the inverse of the number of variables to give the geometric mean index share rule:

$$S_i = \frac{P_i^{\frac{1}{3}} MVI_i^{\frac{1}{3}} \omega_i^{\frac{1}{3}}}{\sum_{i=1}^{N} P_i^{\frac{1}{3}} MVI_i^{\frac{1}{3}} \omega_i^{\frac{1}{3}}} . \quad (4)$$

Geometric means have several desirable properties, including invariance to scale of variable measurement and imperfect substitutability between variables compared to linear aggregation.

In the relevant sharing rules (3)-(4), the generic distribution weight ω_i is replaced by equality of outcome $\omega_i(EO) = \left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$, inequality of opportunity unfair income distribution weights $\omega_i(IO_p) = \frac{\widehat{GNI}_i}{\overline{GNI}}$ *and* $\omega_i(IO_p^U) = \frac{\widehat{GNI}_i}{\overline{\widehat{GNI}}}$, and generalized proportionality distribution weight $\omega_i(IO_p^{GP}) = \frac{\widehat{GNI}_i^R}{\sum_{i=1}^{N} \widehat{GNI}_i^R}$.

15. Intra-Generational Sharing Empirical Results: Summary

1. The geometric mean compared to the alternative mathematical specification of the royalty sharing rules in all cases gives a more compact range from minimum to maximum, less skewness, and greater global social welfare and equality in outcome among individual States Parties for the distributed royalty shares S_i. *Technical Study* 31 gave the same recommendation.

2. Using distribution weights to compensate for inequality of opportunity to participate in deep-seabed mining gives greater global social welfare and equality of outcome among individual States Parties for the distributed royalty shares S_i compared to the equality of outcome distribution weight.

3. The three geometric mean sharing rules using distribution weights to compensate for inequality of opportunity to participate in deep-seabed mining give virtually identical global social welfare and equality of outcome among individual States Parties for the distributed royalty shares S_i.

4. The recommended geometric mean sharing rule uses the inequality of opportunity distribution weight unfair GNI_i / mean observed GNI_i, $\omega_i(IO_p) = \frac{\widehat{GNI}_i}{\overline{GNI}}$. This

distribution weight is closest to conventional approaches to inequality of opportunity, the denominator basis of comparison $\overline{GNI}$ includes both fair and unfair GNI_i. In contrast to Generalized Proportionality, this distribution weight is estimated from more widely available circumstance (non-responsibility) variables rather than responsibility variables.

5. Sharing rules using the equality of outcome distribution weight observed GNI_i / mean observed $GNI_i, \eta = 1, \omega_i(EO) = \left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta=1}$, should use the normative stated preference parameter $\eta = 1$ rather than the less progressive revealed preference parameter $\eta = 0.0001017$. Paradoxically (explained below) royalty shares using the less progressive $\eta = 0.0001017$ give greater equality of outcome among individual States Parties for the distributed royalty shares S_i. But the results are in some sense artificial. *Technical Study* 31 gave the same recommendation.

6. A statistical analysis shows that States Party share of population P_i has several orders of magnitude greater average marginal effect upon distributed royalty share among States Parties S_i than the distribution weight or MVI_i for all geometric mean formulae.[27] The average marginal impacts from: (1) population share P_i are always statistically significant and positive, (2) MVI sometimes statistically significant and sometimes not and sometimes positive and more often negative, and (3) distribution weight sometimes statistically significant and sometimes not and always positive. There is no statistically significant difference in distribution among ISA regions in sharing rules incorporating inequality of opportunity (through distribution weight) although there is in the sharing rule based upon equality of outcome (distribution weight).

7. Statistically significant pairwise correlation coefficients show population share P_i has twice the correlation with distributed royalty share among States Parties S_i as do the distribution weight or MVI_i for all geometric mean formulae.

8. The ranking of equality of outcome distribution for distributed royalty shares S_i among States Parties by ISA region from the most to least equality of outcome by Generalized Entropy equity metric is:

16. Intra-Generational Sharing Empirical Results in Full

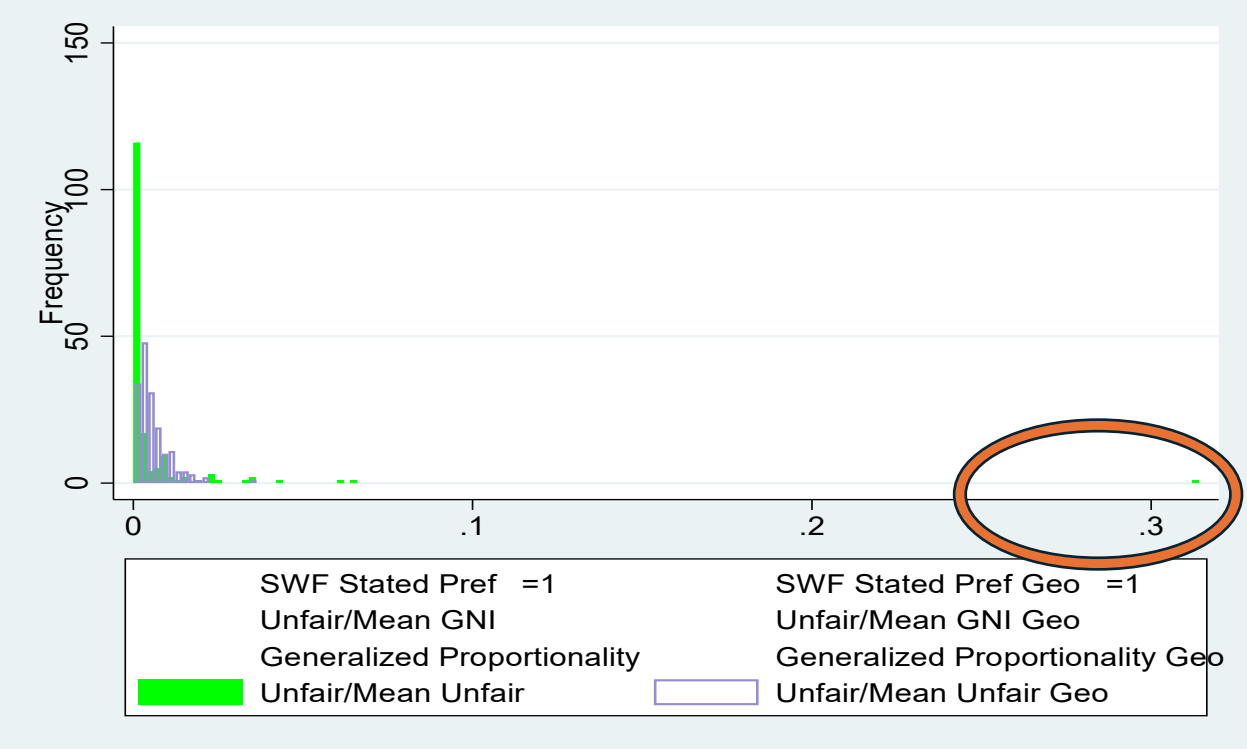
The geometric mean compared to the alternative mathematical specification of the royalty sharing rules in all cases gives a more compact range from minimum to maximum distributed royalty shares S_i and greater equality of outcome in royalty share S_i

[27] Average marginal impacts calculated from fractional logit regression by generalized linear model (glm) with a logit link and the binomial family. Robust standard errors clustered on each ISA regional group calculated by delta method.

distribution among States Parties measured by skewness and other summary statistics (Table 1) and equity metrics (Table 2). *Technical Study 31* reached the same conclusion.

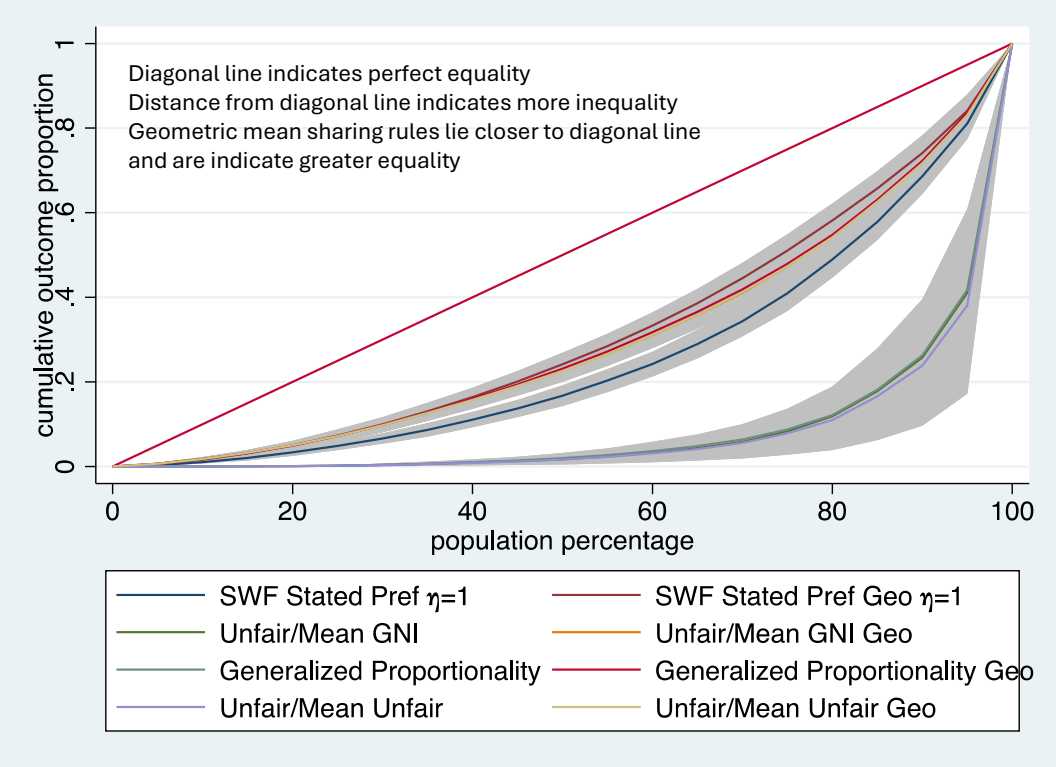
In the following histogram Figure 1 below illustrating this result, note the extreme values of the royalty share S_i on the right-hand side of the distribution receiving over 25% of shares. (GEO at the end of a share name indicates geometric mean and absence indicates no geometric mean.)

Figure 1. Histogram of All Allocated Royalty Shares S_i



The following Lorenz Curves Figure 2 below similarly illustrates that geometric mean sharing rules give greater equality of outcome for distributed royalty shares S_i. The diagonal line indicates perfect equality and the further the Lorenz Curve from this diagonal perfectly equitable diagonal the greater the inequality of share distribution among States Parties. Some lines lie on top of others indicated strict equality in comparison to one another (but not the perfect equality of the diagonal line).

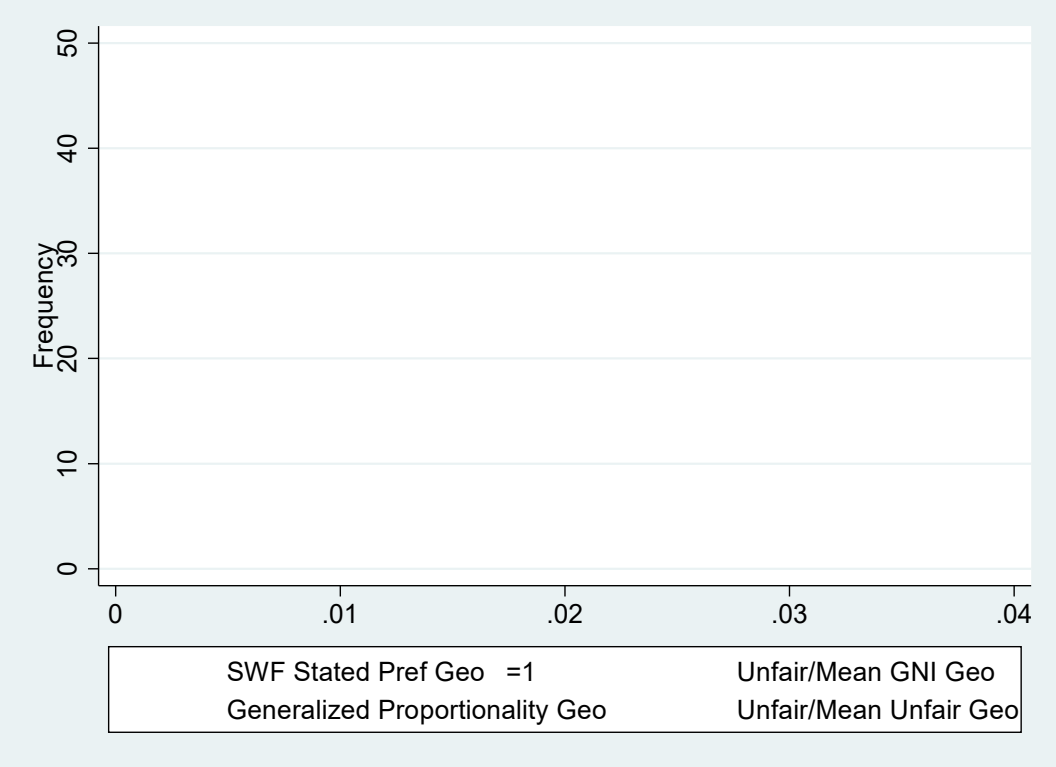
Figure 2. Lorenz Curves for All Allocated Royalty Shares



The follow histogram Figure 3 below illustrates the four final geometric mean royalty sharing rules (defined by their distribution weights). Through their distribution weights, three rules incorporate compensation for inequality of opportunity to participate in deep-seabed mining and one does not, instead incorporating equality of outcome in terms of GNI_i.

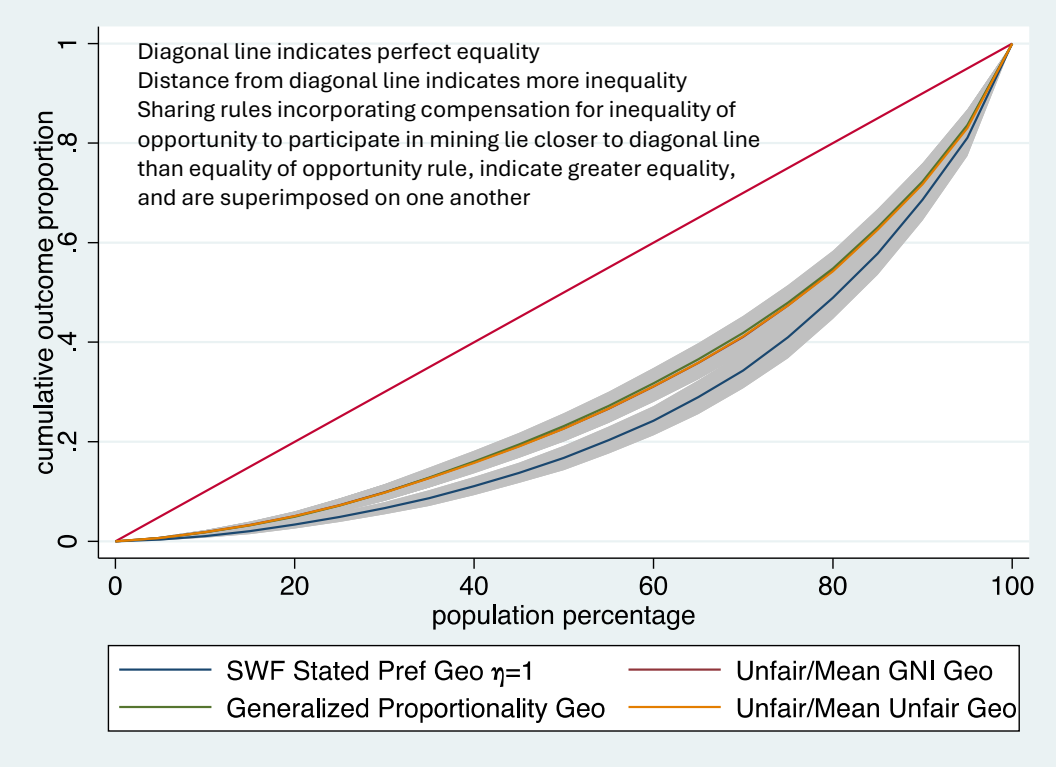
On the histogram Figure 3, the sharing rule defining inequality of opportunity by unfair GNI_i / mean observed GNI_i has a smaller extreme value of S_i than the others. The histogram corresponds to the following skewness measures of S_i ranked lowest to highest: equality of outcome among S_i 1.93, generalized proportionality 2.03, unfair /mean observed GNI_i 2.07, unfair / mean unfair GNI_i 2.27. While informative, skewness measures do not evaluate equality of outcome in royalty share distribution among States Parties S_i. To that end, equity metrics and the Lorenz Curve are required.

Figure 3. Histogram of Allocated Geometric Mean Royalty Shares S_i



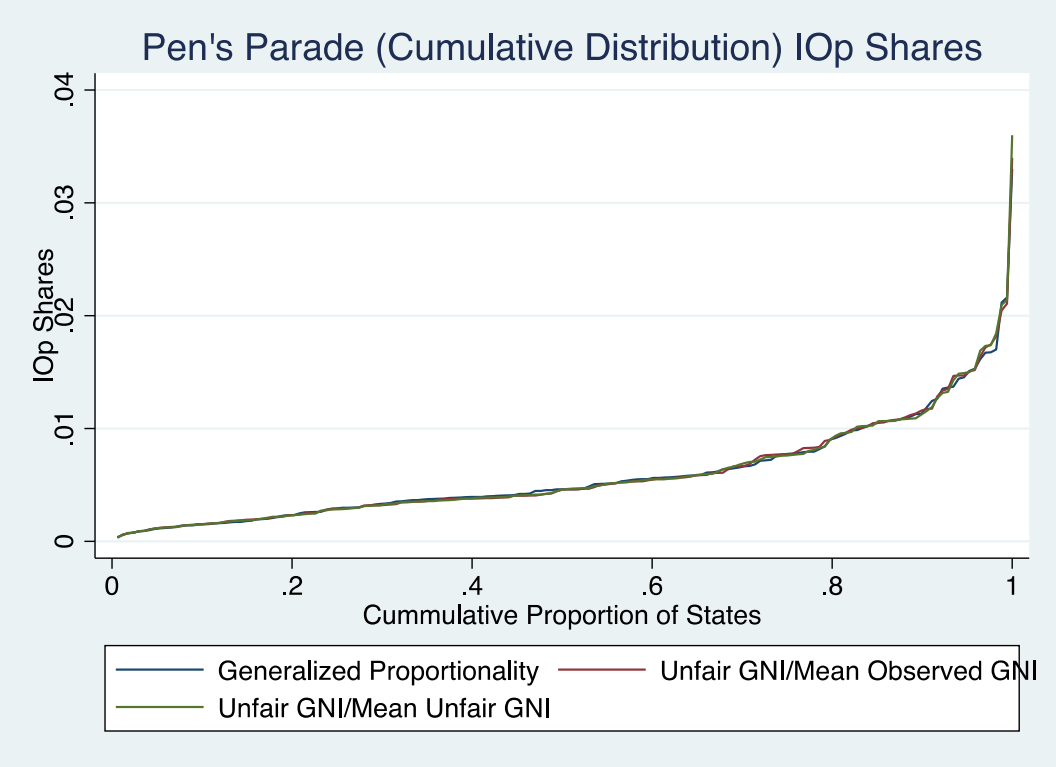
The following Lorenz Curves Figure 4 below demonstrate that distributed royalty shares S_i from the three inequality of opportunity sharing rules are bunched tightly together and the equality of outcome sharing rule (SWF Stated Pref Geo $\eta = 1$) is demonstrably less equitable. The issue now shifts to whether there are any meaningful differences in equality of outcome for distributed royalty shares among States Parties S_i among the three sharing rules compensating for inequality of opportunity.

Figure 4. Lorenz Curves of Allocated Geometric Mean Inequality of Opportunity Royalty Shares S_i



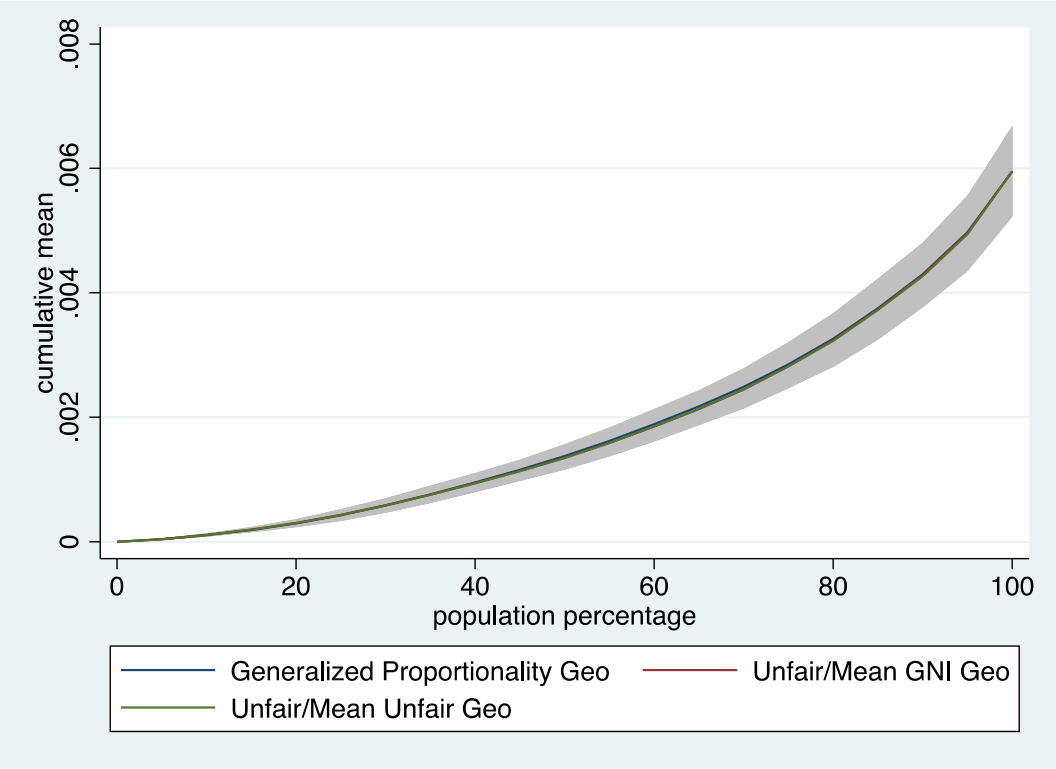
Pen's Parade in Figure 5 below is another way to evaluate and illustrate equality of outcome for the distributed geometric mean inequality of opportunity royalty shares among the States Parties S_i. Pen's Parade is defined as a succession of every States Party royalty share S_i, with their height proportional to their distributed share and ordered from lowest shares to largest share S_i sizes. If the line-ups of shares S_i in the 'parade' are closer in size, then equality of outcome is close. Conversely, the more the line-ups of shares S_i in the 'parade' diverge the greater the inequality of outcome in distribution of royalty shares S_i. The results show that the three sharing rules 'parade' in virtual lockstep and are difficult if not impossible to distinguish from one another. No sharing rule stands heads and shoulder above another in the 'parade'.

Figure 5. Pen's Parade of Allocated Geometric Inequality of Opportunity Mean Royalty Shares



Generalized Lorenz Curves are like Lorenz Curves, but their construction allows direct inferences on social welfare besides equality of outcome in distribution of royalty shares to States Parties S_i. To more closely identify equality of outcome rankings of the three inequality of opportunity sharing rules, the following Generalized Lorenz Curves in Figure 6 below for the three inequality of opportunity sharing rules distributed royalty shares S_i illustrates that distributions and social welfare are virtually indistinguishable.

Figure 6. Generalized Lorenz Curves of Allocated Geometric Mean Inequality of Opportunity Royalty Shares S_i



To try to make sense of equality of outcome for the sharing rules, this report turns to equity metrics. Equity metric evaluation of royalty share S_i equality of outcome for individual States Parties ranks the four final geometric mean royalty sharing rules (defined by their distribution weights) from highest to lowest (Table 2): [unfair GNI_i / mean observed GNI_i] > [unfair GNI_i / mean unfair GNI_i] = [Generalized Proportionality] > [observed GNI_i / mean observed GNI_i, $\eta = 1$], i.e. $\omega_i(IO_p) = \frac{\widehat{GNI}_i}{\overline{GNI}} > \omega_i(IO_p^U) = \frac{\widehat{GNI}_i}{\overline{\widehat{GNI}}} = \omega_i(IO_p^{GP}) = \frac{\widehat{GNI}_i^R}{\sum_{i=1}^N \widehat{GNI}_i^R} > \omega_i(EO) = \left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta=1}$. Broad conclusions are that sharing rules incorporating compensation for inequality of opportunity give greater equality of outcome for distributed royalty shares S_i than does the standard equality of outcome distribution weight $\omega_i(EO) = \left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta=1}$. The distribution rule incorporating compensating inequality of opportunity [unfair GNI_i / mean observed GNI_i], i.e. $\omega_i(IO_p) = \frac{\widehat{GNI}_i}{\overline{GNI}}$, gives greatest equality of outcome for distributed royalty shares among States Parties. Moreover, this distribution weight is most consistent with standard practice in the literature (Ferreira and Peragine 2016).

Statistical testing for differences in the four sharing rules (Lorenz Dominance tests) gives a very similar final ranking from most equitable to least equitable in terms of inequality of outcome in royalty share distribution among States Parties (Table 4). The difference is that

the first two sharing rules change places to give: [unfair GNI_i / mean unfair GNI_i] > [unfair GNI_i / mean observed GNI_i] = [Generalized Proportionality] > [observed GNI_i / mean observed GNI_i, $\eta = 1$], i.e. $\omega_i(IO_p^U) = \frac{\widehat{GNI}_i}{\widehat{\overline{GNI}}} > \omega_i(IO_p) = \frac{\widehat{GNI}_i}{\widehat{\overline{GNI}}} = \omega_i(IO_p^{GP}) = \frac{\widehat{GNI}_i^R}{\sum_{i=1}^{N}\widehat{GNI}_i^R} > \omega_i(EO) = \left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta=1}$. Nonetheless, while there are statistically significant differences among the three inequality of opportunity sharing rules, the distance between them is for all practical purposes indistinguishable.

A final way to evaluate the difference in equity of distributed shares S_i between the three inequality of opportunity sharing rules distribution among States Parties is given by the Generalized Entropy equity metric ($J1$, income parameter a = income difference sensitivity parameter = 1) that evaluates the difference between the three different distributed shares S_i with one of them serving as a norm reference share, here the distribution of royalty shares S_i using the distribution weight Unfair GNI_i / Mean Observed GNI_i or $\omega_i(IO_p) = \frac{\widehat{GNI}_i}{\widehat{\overline{GNI}}}$ (Cowell 1985, Devooght 2008 Equation 3.1). The distances between the distribution of shares S_i for the two inequality of opportunity shares S_i with the norm distribution of S_i are negligible, indicating that they are virtually equal: $J1$ = 0.0003968 for Unfair GNI_i / Mean Observed GNI_i and $J1$ = 0.0024543 for Generalized Proportionality. The distance with observed GNI_i / mean observed GNI_i, $\eta = 1$ is demonstrably larger at $J1$ = 0.3586871.

Since the three inequality of opportunity royalty sharing rules give such close results, this report recommends using the geometric mean sharing rule incorporating the distribution weight Unfair GNI_i / Mean Observed or GNI_i $\omega_i(IO_p) = \frac{\widehat{GNI}_i}{\widehat{\overline{GNI}}}$. This rule is estimated using only circumstance variables rather than the responsibility variables of Generalized Proportionality. There are far more circumstance than responsibility variables available from the World Bank Development Indicators database, which in turn allows greater choice and use of reliable variables in the machine learning random forest predictions.[28] The denominator in the distribution weight GNI_i / Mean Observed GNI_i, i.e., $\omega_i(IO_p) = \frac{\widehat{GNI}_i}{\widehat{\overline{GNI}}}$, includes both unfair and fair GNI_i which is the norm in the literature (Roemer and Trannoy 2015, Ferreira and Peragine 2016). Mean Observed GNI_i stands in contrast to Mean Unfair GNI_i which excludes fair GNI_i.

The stated preference progressivity parameter value $\eta = 1$ is recommended over the revealed preference progressivity parameter value $\eta = 0.0001017$ and the stated preference value $\eta = 2$ in the social welfare function equality of outcome distribution weight $\omega_i(EO) = \left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$ and equality of outcome sharing rules. Raising the value of progressivity parameter η paradoxically creates proportionately more losers than gainers among States Parties that outweigh the more limited number of gainers enjoying

[28] Overfitting is acceptable here because out-of-sample predictions and random forest training on part of the sample for such predictions are not required. The predictions are not used to determine the future.

considerable gains in allocated share S_i. The Appendix develops this result in greater detail. *Technical Report* 31 reached the same conclusion.

17. Article 82 Sharing Rules

Article 82 'Payments and contributions with respect to the exploitation of the continental shelf beyond 200 nautical miles' states that, 'The payments or contributions shall be made through the Authority, which shall distribute them to States Parties to this Convention, on the basis of equitable sharing criteria, taking into account the interests and needs of developing States, particularly the least developed and the land-locked among them."

'Developing States, particularly the least developed and the land-locked among them', clearly face inequality of opportunity to participate in deep-seabed mining due to circumstances beyond their responsibility or control. Hence, UNCLOS Article 140 methodology applies with some small modifications presented here but without empirical application. The Article 82 approach differs depending on whether the distribution weight compensates for inequality of opportunity or implements equality of opportunity.

The inequality of opportunity distribution weights' unfair income is predicted by the random forest approach with an additional variable, a dummy variable for the 10 ISA least developed and landlocked States Parties (Burkina Faso, Chad, Lao PDR, Lesotho, Malawi, Mali, Nepal, Niger, Uganda, and Zambia). Everything else remains the same.

The equality of outcome distribution weight follows the approach of *Technical Study* 31 by using a different value for the progressivity parameter η that can be from either revealed ethical preferences of the UN General Assembly annual budget assessments or ISA stated preferences for η. UN revealed ethical preferences for η are estimated the same way as Article 140 except that a dummy variable for least developed and landlocked States Parties interacting with GNI_i is included in the estimated equation and nonlinear assessment. The resulting $\eta = 0.0000565$ is also effectively Utilitarian (like Article 140), meaning that equitable distribution is for the greatest good regardless of distributional impact. As with Article 140, this report recommends use of stated preference η and consistent with *Technical Report* 31, this report recommends stated preference $\eta = 1.1$.

18. Sustainable Development as the Framework to Integrate Intra-Generational and Inter-Generational Sharing

Sustainable development balances economic, social, and environmental needs to ensure and balance the well-being of current and future generations (Dasgupta 2021). It is based on the premise that development should satisfy current generation well-being without compromising the well-being of future generations. It accounts for all forms of capital (natural minerals and environment, produced, and human) and inclusive wealth from this capital.

Dasgupta's (2021) sustainable development framework is grounded in the belief that economies are not external to nature but part of it. Dasgupta's framework, rooted in the 1987 Brundtland Commission report, is expanded by its economic framework. This framework shifts sustainability from economic growth accounting for environmental adjustments to prosperity (measured as inclusive wealth of natural, produced, and human capital) within ecological limits.

Dasgupta argues that natural capital is the most critical form of capital. Natural capital (that underpins life and economic activity) includes ecosystems, biodiversity, soil, air, minerals and metals, flora and fauna, etc. Produced capital is infrastructure, machines, etc. Human capital is education, skills, etc. True sustainability requires that total inclusive wealth per capita does not decline over time. Each generation must pass on a "productive base" (of natural, produced, and human capital) at least as robust as the one it inherited, relative to population size.

A sustainable development objective thus stipulates that there be no decline in sustainable inter-generational per capita wellbeing and inclusive wealth (natural, produced, and human capital) (Dasgupta 2021). This objective, following Dasgupta's (2021) natural-capital-centric framework, can be reached by investing mining royalties in human and reproducible capital. Specifically, capital value losses from the drawdown of mineral and environmental natural capital must be offset with equivalent investments in other forms of capital following the Hartwick (1977) rule. The ISA could operationalize that objective by setting a mining rate that balances current consumption from mining with *in situ* savings (by not mining) of all natural capital stocks, while investing the mining royalties in a sustainable resource fund that invests in human and reproducible capital as global public goods and/or for future consumption. This rule requires accounting for any environmental and other external costs. Beyond such a sustainable development mandate, inter-generationally equitable distribution can occur through the ISA discount rate if 3.75% developed in Freeman et al. (2020).

Should the CHH principle be interpreted as accounting for humankind in general and throughout the globe and not simply confined to the Area and mining, then the sustainable development framework can be expanded to include spillover impacts onto terrestrial mining (including environmental and social costs), recycling and reuse, and mineral supply impacting climate change and its external costs. A portfolio approach balances discounted accounting-priced (valuation of mining and climate change externalities) net benefits across deep-seabed and terrestrial mining and recycling and reuse Dasgupta 2021).

Whichever framework is chosen, it is clearly only qualitative and faces considerable challenges. Many of the external costs involved in mining both the terrestrial and deep-sea environments are damages to natural capital that are difficult to quantitatively value.

Uncertainty poses a significant challenge for optimal policy even greater than external cost valuation. While terrestrial mining impacts may be better understood than deep-seabed mining, both are subject to pervasive uncertainty over the incidence, magnitude, and probability of environmental impacts. There is also the possibility of discontinuous costs generated by potential irreversible environmental impacts, most notably extinction from both terrestrial and deep-seabed mining. As the precise triggers of these extinctions are unknown, they cannot easily be accounted for in an optimal portfolio. There are generally greater uncertainties for the deep seabed about species existence and valuation, mining impacts, and extinction thresholds and in the technologies that can be developed to reduce deep seabed mining environmental impacts. Mineral supply chains, whether land or sea, are as a rule fraught with risk and uncertainty due to high investment costs with long horizons, market volatility and supercycles, and geopolitical and regulatory unpredictability. The impact of mineral supply upon climate change is similarly fraught with pervasive risk and uncertainty.

Perhaps the key ISA challenge when implementing sustainable development as an integrated intra- and inter-generational sustainable development framework is balancing the considerable uncertainties found with deep-seabed and terrestrial mining, recycling and reuse of minerals, and future climate change. Mining creates uncertainties but not mining creates spillovers with uncertainties, opportunity costs, and trade-offs that must be weighed. No simple task.

19. Tables

Table 1. Sharing Rule Summary Statistics

Share Equation	Equation Number	Distribution Weight	Mean	Median	Standard Deviation	Minimum	Maximum	Skewness[29]
Equal Division	(1)	None	0.0059524	0.0063954	0.001122	0.0043418	0.0075069	-0.59499
Proportional	(2)	None	0.0059524	0.0009874	0.0239192	1.89e-07	0.2164766	8.115735
Proportional Geometric Mean but without Distribution Weight	(3)	None	0.0059524	0.0038871	0.0074827	0.0000538	0.0575562	4.245104
Equality of Outcome Revealed Preference Weighted Proportional $\eta = 0.0001017$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	0.0059524	0.0009874	0.0239191	1.89e-07	0.2164927	8.115666

[29] Skewness measures asymmetry of the distribution of values in a dataset. It indicates whether the data are negatively skewed to the left or the positively skewed to the right relative to the mean. In a positively skewed distribution, the tail on the right side (the larger values) is longer than the tail on the left side (the smaller values). This means that most observations are concentrated on the left side of the distribution with some extreme values on the right-hand side.

Equality of Outcome Revealed Preference Weighted Proportional Geometric Mean $\eta = 0.0001017$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	0.0059524	0.0050199	0.0044585	0.0002893	0.0302709	2.264336
Equality of Outcome Stated Preference Weighted Proportional $\eta = 1$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	0.0059524	0.0003523	0.0228734	3.86e-08	0.2620727	8.935811
Equality of Outcome Stated Preference Weighted Proportional Geometric Mean $\eta = 1$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	0.0059524	0.0040791	0.0057125	0.0001951	0.0369629	1.931548
Equality of Outcome Stated Preference Weighted Proportional $\eta = 2$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	0.0059524	0.0000361	0.0212366	2.75e-10	0.1803441	5.759046
Equality of Outcome Stated Preference Weighted Proportional Geometric Mean $\eta = 2$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	0.0059524	0.0023679	0.0076987	0.0000467	0.0405715	2.081228
Inequality of Opportunity Unfair Income / Mean Observed Income	(4)	$\frac{\widehat{GNI}_i}{\overline{GNI}}$	0.0059524	.0006924	0.0233596	3.72e-07	.02795268	9.894783
Inequality of Opportunity Unfair Income / Mean Observed Income Geometric Mean	(4)	$\frac{\widehat{GNI}_i}{\overline{GNI}}$	0.0059524	.0045993	0.0047655	0.000374	0.0339926	2.0733
Inequality of Opportunity Unfair Income / Mean Unfair Income	(4)	$\frac{\widehat{GNI}_i}{\overline{\widehat{GNI}}}$	0.0059524	0.000657	0.025744	2.87e-07	0.313951	10.46467

Inequality of Opportunity Unfair Income / Mean Unfair Income Geometric Mean	(4)	$\frac{\widehat{GNI}_i}{\overline{\widehat{GNI}}}$	0.0059524	0.004603	0.004846	0.0003493	0.0359918	2.271591
Inequality of Opportunity Generalized Proportionality	(4)	$\frac{\widehat{GNI}_i^R}{\overline{\sum_{i=1}^N \widehat{GNI}_i^R}}$	0.0059524	0.0007168	0.0225498	2.15e-07	0.2652242	9.488882
Inequality of Opportunity Generalized Proportionality Geometric Mean	(4)	$\frac{\widehat{GNI}_i^R}{\overline{\sum_{i=1}^N \widehat{GNI}_i^R}}$	0.0059524	0.0045992	0.004686	0.0003079	0.033018	2.031477

Generalized Entropy indices $GE(a)$ are a function of a = income difference sensitivity parameter. Lower a gives greater importance to lower-income States Parties. The Generalized Entropy index ranges between 0 and infinity, with lower values indicating greater equality and greater social welfare. Atkinson indices, $A(e)$, are a function of $e > 0$, the inequality aversion parameter. Lower e gives greater importance to lower income States Parties. The Atkinson index ranges between 0 and 1, with lower values indicating greater equality and social welfare. The Gini coefficient ranges between 0 and 1, with lower values indicating greater equality. Although not reported here, all Gini coefficients are statistically significantly different from 0.

The following Table 2 summarizes the equity indices for the different sharing rules. Values in parenthesis from 1-10 for the different indices indicates the ranking of the sharing rules from most to least equitable in equality of outcome for royalty share distribution among States Parties S_i. The different equity metrics largely give the same ranking to each sharing rule.

Table 2. Summary of Equity Indices for Different Sharing Rules

Share Equation	Equation Number	Distribution Weight	Generalized Entropy GE(0)	Generalized Entropy GE(1)	Atkinson A(0.5)	Atkinson A(1)	Gini Coefficient
Equal Division	(1)	None	0.01960 (1)	0.01852 (1)	0.00949 (1)	0.01941(1)	0.10018 (1)
Proportional	(2)	None	2.09031 (8)	1.80460 (9)	0.61103 (8)	0.87635 (8)	0.82336 (8)
Proportional Geometric Mean	(3)	None	0.57303 (7)	0.49554 (7)	0.23011 (7)	0.43619 (7)	0.51790 (7)
Equality of Outcome Revealed Preference Weighted Proportional $\eta = 0.0001017$	(3)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	2.09035 (9)	1.80460 9)	0.61103 (8)	0.87636 (9)	0.82336 (8)

Equality of Outcome Revealed Preference Weighted Proportional Geometric Mean $\eta = 0.0001017$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	0.26831 (2)	0.23643 (2)	0.11740 (2)	0.23533 (2)	0.37263 (2)
Equality of Outcome Stated Preference Weighted Proportional $\eta = 1$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	3.04017 (13)	1.88404 (11)	0.68837 (13)	0.95217 (13)	0.86415 (13)
Equality of Outcome Stated Preference Weighted Proportional Geometric Mean $\eta = 1$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	0.44888 (6)	0.38200 (6)	0.18734 (6)	0.36166 (6)	0.47856 (6)
Equality of Outcome Stated Preference Weighted Proportional $\eta = 2$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	4.76557 (14)	2.09627 (14)	0.77909 (14)	0.99148 (14)	0.90384 (14)
Equality of Outcome Stated Preference Weighted Proportional Geometric Mean $\eta = 2$	(4)	$\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$	4.76557 (14)	2.09627 (14)	0.77909 (14)	0.99148 (14)	0.90384 (14)
Inequality of Opportunity Unfair Income / Mean Observed Income	(4)	$\frac{\widehat{GNI}_i}{\overline{\widehat{GNI}}}$	2.23786 (10)	1.77867 (8)	0.63000 (10)	0.89331(10)	0.83874 (10)
Inequality of Opportunity Unfair Income / Mean Observed Income Geometric Mean	(4)	$\frac{\widehat{GNI}_i}{\overline{\widehat{GNI}}}$	0.28670 (3)	0.26540 (3)	0.12878 (3)	0.24926 (3)	0.39923 (3)
Inequality of Opportunity Unfair Income / Mean Unfair Income	(4)	$\frac{\widehat{GNI}_i}{\overline{\widehat{\widehat{GNI}}}}$	2.30073 (11)	1.89969 (12)	0.64720 (11)	0.89981 (11)	0.84875 (11)

Inequality of Opportunity Unfair Income / Mean Unfair Income Geometric Mean	(4)	$\frac{\widehat{GNI}_i}{\overline{\widehat{GNI}}}$	0.28922 (4)	0.26927 (4)	0.13007 (4)	0.25116 (4)	0.40055 (4)
Inequality of Opportunity Generalized Proportionality	(4)	$\frac{\widehat{GNI}_i^R}{\sum_{i=1}^{N} \widehat{GNI}_i^R}$	2.30073 (11)	1.89969 (12)	0.64720 (11)	0.89981 (11)	0.84875 (11)
Inequality of Opportunity Generalized Proportionality Geometric Mean	(4)	$\frac{\widehat{GNI}_i^R}{\overline{\sum_{i=1}^{N} \widehat{GNI}_i^R}}$	0.28922 (4)	0.26927 (4)	0.13007 (4)	0.25116 (4)	0.40055 (4)

Table 3. Circumstance and Responsibility Variables

Variable	Source	Circumstance / Responsibility	No. Observations	Mean
Life Expectancy at Birth, SDG3, 2022 LIFE_EXPECT_HDI2022	HDI WBDI	Circumstance	165	71.94
Expected Years Schooling Children of Age 5 Entering Education System, SDG4.3, 2022 EXPECT_SCHOOL_HDI2022	HDI WBDI	Circumstance	165	17.30
Probability of Survival to Age 5 for 2018 SURVIVAL_AGE5_HCI2020	HCI WBDI	Circumstance	152	0.97
Human Capital Index HCI_2020	HCI WBDI	Circumstance	151	0.5606
Access to Electricity (% of Population) ACCESS_ELEC	HOI WBDI	Circumstance	166	86.17
People Using Safely Managed Sanitation Services (% of Population) SANITATION	HOI WBDI	Circumstance	111	58.53016
Strength of Institutions (0=Weak, 12=Strong) STRENGTH_INST_2019	WBDI	Circumstance	161	5.59
Labor force, female (% of total labor force) GENDER	WBDI	Circumstance	153	41.61869
Gross capital formation % GDP CAPITAL	WBDI	Circumstance	143	23.81944
Agricultural Land % Land Area LAND	WBDI	Circumstance	163	113.8342
Urban Population as % Total Population URBAN	WBDI	Circumstance	165	60.27049
Population Share POPSHARE	UN FAO	Circumstance	168	0.0059524
Multivariate Vulnerability Index MVI	UN	Circumstance	168	.370952
Median Age of Population AGE	ILO	Circumstance	168	41.64881
Median Age of Population Squared AGE2	ILO	Circumstance	168	25,285.03
Dummy Variable Least Developed DLEASTDEV	ISA	Circumstance	168	0.1607143
Dummy Variable Developing Landlocked DLLDCISA	ISA	Circumstance	168	0.125
Dummy Variable Africa Group DAFRICA	ISA	Circumstance	168	0.1785714
Dummy Variable Asia-Pacific Group DAPG	ISA	Circumstance	168	0.1488095
Dummy Variable Latin America and Caribbean Group DGRULAC	ISA	Circumstance	168	0.1845238
Dummy Variable Eastern Europe Group DEEG	ISA	Circumstance	168	0.1309524
Dummy Variable Western Europe and Others Group DWEOG	ISA	Circumstance	168	0.1428571

Dummy Variable Pacific Island Small Island Developing States DPSID	ISA	Circumstance	168	0.0595238
Mean Years Schooling, 2022 MEAN_SCHOOL_HDI2022	HDI WBDI	Responsibility	165	9.1
Mean Years of Schooling Completed for Adults Aged 5, SDG4.4, 2022 ADJUST_SCHOOL_HCI2020	HDI WBDI	Responsibility	152	7.776752
Harmonized Test Scores for 2020 TEST_SCORES_HCI2020	HCI WBDI	Responsibility	152	421.362
SURVIVAL_RATE_HCI2020	HCI WBDI	Responsibility	152	0.8464751
Average hours per week per employed person HOURS_WORKED	ILO	Responsibility	137	39.77883
Share of employed working 49 or more hours per work EMPLOYED49	ILO	Responsibility	131	0.1683969

Note: HCI (World Bank Human Capital Index), HDI (World Bank Human Development Index), HOI (World Bank Human Opportunity Index), ILO (International Labor Organization), FAO (Food and Agriculture Organization of the UN). HCI, HDI, and HOI variables data sourced from WBDI (World Bank Development Indicators). Dummy variables are not perfectly exclusive (generating some multicollinearity).

Table 4. Lorenz Dominance Tests of Different Geometric Mean Sharing Rules for S_i

X-Variable (Type of Sharing Rule Distribution Weight)	Y-Variable (Type of Sharing Rule Distribution Weight)	Test of Weak Dominance $(X \geq Y)$ or Equality $(X = Y)$?	Test Statistic	p-Value	Reject Null Hypothesis of X versus Y ? (Yes/No)	Conclusion
Unfair GNI_i /Mean Unfair GNI_i	Unfair GNI_i /Mean Observed GNI_i	Weak Dominance	0.0000	1.0000	No	$X \geq Y$
Unfair GNI_i /Mean Unfair GNI_i	Unfair GNI_i /Mean Observed GNI_i	Equality	2.67461	0.0000	Yes	$X > Y$
Unfair GNI_i /Mean Unfair GNI_i	Generalized Proportionality	Weak Dominance	0.0000	1.0000	No	$X \geq Y$
Unfair GNI_i /Mean Unfair GNI_i	Generalized Proportionality	Equality	2.60679	0.0000	Yes	$X > Y$
Unfair GNI_i /Mean Unfair GNI_i	GNI_i / Mean GNI_i $\eta = 1$	Weak Dominance	0.0000	1.0000	No	$X \geq Y$
Unfair GNI_i /Mean Unfair GNI_i	GNI_i / Mean GNI_i $\eta = 1$	Equality	3.30611	0.0000	Yes	$X > Y$
Unfair GNI_i /Mean Observed GNI_i	Generalized Proportionality	Weak Dominance	0.0000	1.0000	No	$X \geq Y$

Unfair GNI_i /Mean Observed GNI_i	Generalized Proportionality	Equality	2.60679	0.0000	Yes	$X > Y$
Unfair GNI_i /Mean Observed GNI_i	GNI_i / Mean GNI_i $\eta = 1$	Weak Dominance	0.0000	1.0000	No	$X \geq Y$
Unfair GNI_i /Mean Observed GNI_i	GNI_i / Mean GNI_i $\eta = 1$	Equality	3.30611	0.0000	Yes	$X > Y$
Generalized Proportionality	GNI_i / Mean GNI_i $\eta = 1$	Weak Dominance	0.0000	1.0000	No	$X \geq Y$
Generalized Proportionality	GNI_i / Mean GNI_i $\eta = 1$	Equality	3.30611	0.0000	Yes	$X > Y$

Note: Kolmogorov-Smirnov type test statistic based on the largest positive difference LC_(y)-LC_(x), i.e., the standardized largest difference between the two sample's Lorenz curves. The empirical bootstrap (500 times) is used to simulate the distribution of each test statistic and thereby calculate the corresponding p-values.

Table 5. Average Marginal Impacts Upon Distributed Royalty Shares S_i

GNI_i / Mean Observed GNI_i $\left[\frac{\overline{GNI}}{GNI_i}\right]^{\eta}$				
Variable	Coefficient	Robust Standard Error	Z	P > |Z|
Dummy Variable Africa	.0013868	.0001111	12.48	0.000
Dummy Variable Latin America Caribbean	-.0004126	.000981	-0.42	0.674
Dummy Variable Eastern Europe	-.0027143	.0011489	-2.36	0.010
Dummy Western Europe	-.0047554	.0013245	-3.59	0.000
Population Share	.058318	.0015305	38.10	0.000
MVI	-.0033201	.0020012	-1.66	0.097
Distribution Weight	.000296	.0000507	5.84	0.000
Unfair GNI_i / Mean Observed GNI_i $\frac{\widehat{GNI}_i}{\overline{GNI}}$				
Variable	Coefficient	Robust Standard Error	Z	P > |Z|
Dummy Variable Africa	.0004553	.0007239	0.63	0.529
Dummy Variable Latin America Caribbean	.0003233	.0008644	0.37	0.708
Dummy Variable Eastern Europe	-.000918	.0013158	-0.70	0.485
Dummy Western Europe	.0003992	.0018624	0.21	0.830
Population Share	.0589623	.0066661	8.85	0.000
MVI	-.0055857	.0021139	-2.64	0.008
Distribution Weight	.0005854	.000653	0.90	0.370
Unfair GNI_i / Mean Unfair GNI_i $\frac{\widehat{GNI}_i}{\widehat{\overline{GNI}}}$				

Variable	Coefficient	Robust Standard Error	Z	P > |Z|
Dummy Variable Africa	.0005643	.000718	0.79	0.432
Dummy Variable Latin America Caribbean	.0003584	.0008706	0.41	0.681
Dummy Variable Eastern Europe	-.0009205	.0012786	-0.72	0.472
Dummy Western Europe	.0001104	.0018085	0.06	0.951
Population Share	.0599877	.0066944	8.96	0.000
MVI	-.0054113	.00205	2.64	0.008
Distribution Weight	.0006187	.0005428	1.14	0.254
Generalized Proportionality $\frac{\widehat{GNI}_i^R}{\sum_{i=1}^N \widehat{GNI}_i^R}$				
Variable	Coefficient	Robust Standard Error	Z	P > |Z|
Dummy Variable Africa	.0008234	.0007012	1.17	0.240
Dummy Variable Latin America Caribbean	.0002505	.0008703	0.29	0.773
Dummy Variable Eastern Europe	-.0007208	.00126	-0.57	0.567
Dummy Western Europe	-.0004901	.0015729	-0.31	0.755
Population Share	.059282	.0061247	9.68	0.000
MVI	-.0046335	.002016	-2.30	0.022
Distribution Weight	.1580761	.0676728	2.34	0.019

Note: Constant is ISA Asia-Pacific group. Regional dummy variables not statistically significant by Wald tests for inequality of opportunity share equations but statistically significant for equality of opportunity share equation.
Average marginal impacts calculated from fractional logit regression by generalized linear model (glm) with a logit link and the binomial family. Robust standard errors clustered on each ISA regional group calculated by delta method.

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