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On Intergenerational Commitment, Weak Sustainability, and Safety

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Abstract: This article examines sustainability from a policy perspective rooted in environmental economics and environmental ethics. Endorsing the Brundtland Commission stance that each generation should have undiminished opportunity to meet its own needs, I emphasize the foundational status of the intergenerational commitment. The standard concepts of weak and strong sustainability, WS and SS, are sketched and critiqued simply and intuitively, along with the more recent concept of WS-plus. A recently proposed model of a society dependent on a renewable but vulnerable resource (Barfuss et al. 2018) is introduced as an expositional tool, as its authors intended, and used as a platform for thought experiments exploring the role of risk management tools in reducing the need for safety. Key conclusions include: (i) Safety, in this case, the elimination of risk in uncertain production systems, comes at an opportunity cost that is often non-trivial. (ii) Welfare shocks can be cushioned by savings and diversification, which are enhanced by scale. Scale increases with geographic area, diversity of production, organizational complexity, and openness to trade and human migration. (iii) Increasing scale enables enhancement of sustainable welfare via local and regional specialization, and the need for safety and its attendant opportunity costs is reduced. (iv) When generational welfare is stochastic, the intergenerational commitment should not be abandoned but may need to be adapted to uncertainty, e.g., by expecting less from hard-luck generations and correspondingly more from more fortunate ones. (v) Intergenerational commitments must be resolved in the context of intragenerational obligations to each other in the here and now, and compensation of those asked to make sacrifices for sustainability has both ethical and pragmatic virtue. (vi) Finally, the normative domains of sustainability and safety can be distinguished—sustainability always, but safety only when facing daunting threats.

Keywords: sustainability; intergenerational commitment; weak sustainability; strong sustainability; safety; risk management; organizational scale; intragenerational obligations

1. Introduction

1.1. The Sustainability Commitment Is an Intergenerational Obligation

Framing sustainability so as to respect its “forever” dimension requires an intergenerational perspective. The Brundtland Commission concluded that sustainability would be achieved if each generation bequeathed to the next an undiminished opportunity to meet its own needs [1], a stance foreshadowed by Solow [2]. Economists have interpreted needs in terms of welfare opportunities, which should be undiminished [3]. If this commitment is honored by each generation in its turn, the welfare of an unending sequence of generations will be sustained. A generation might be tempted to bequeath a little less in order to consume a little more, and the circumstance of its presence on this earth provides opportunity but not the moral authority to do so. The intergenerational commitment is a moral and ethical obligation.

Several notions of the content of the bequest have been suggested [4, 5]. In its most direct formulation, known as weak sustainability, WS, bequests of non-diminishing inclusive wealth, IW, would permit non-diminishing welfare. Alternatively, sustainability might be viewed as all, or mostly, about sustaining natural resources per se, a position known as strong sustainability, SS [4–6]. One SS approach might seek to identify a few truly critical resources to be sustained as essential complements to WS. At the other end of the SS spectrum, it might be argued that nothing short of a world with its planetary boundaries, PBs, intact is adequate. All of these formulations share a commitment to intergenerational equity: each generation should have equal opportunity to enjoy equal wellbeing—which WS formulations treat as welfare, while SS approaches may honor a variety of value-motivations including respect for nature per se [7, 8]—and the ideal future pathway is the one that would provide each with the highest possible wellbeing consistent with intergenerational equity [9].

The foregoing frames the focus of this article: the economic-theory foundations of WS; the tension between WS and SS re the extent to which sustaining particular natural resources is essential to sustainability; the tension within SS as to motivations for sustainability (is there an obligation to nature per se, independent of human concerns?); and the ethical foundations of the intergenerational commitment upon which sustainability depends.

1.2. What Should We Aspire to Sustain?

1.2.1. Weak Sustainability—Sustaining Welfare by Bequeathing Non-Diminished Inclusive Wealth

WS approaches have in common the idea that what should be sustained is human welfare—technically, a money-metric measure of satisfaction, in which ability to pay has more influence than it perhaps deserves [10]—which can, in principle, be gained from many different combinations of goods, services, and amenities. Sustaining welfare makes intuitive sense when we cannot predict what new processes and products future technology will bring, and what particular goods and services future people will prefer.

Welfare per se is not easy to pass forward through a sequence of generations but wealth, broadly defined, can be transmitted. Welfare can be sustained if each generation bequeaths non-diminishing inclusive wealth—including natural, built and manufactured, financial, human, social, and political capital—to its successor generation [11, 12, 13, 14, 15]. Interpreting WS as an intergenerational commitment to bequeath non-diminishing IW is consistent with the World Commission's [1] concept of sustainability, which urges endowing future generations with the means to meet their own needs.

Wealth accounting frameworks have been developed and implemented. For example, the World Bank's Genuine Savings concept has been implemented in its Adjusted Net Savings and IW accounts, and has informed the United Nations Environmental Program IW accounts, which have been estimated and updated annually for more than 200 countries, in many cases for more than 40 years [16]. IW accounting includes the major forms of capital, implicitly assuming a considerable degree of substitutability among them.

WS raises a variety of issues in principle and in practice. In principle, WS depends on strong assumptions about the substitutability of goods and services in consumption and of different kinds of capital and resources in production [2]. The conceptual literature underpinning WS has been abstract from the beginning. Theorems concerning the necessary and sufficient conditions for WS, and theorems re intergenerational equity, tend to be highly mathematical, heavily caveated, and seldom as conclusive as might be desired. For example, the Solow–Hartwick rule—that net depletion of exhaustible resources should be compensated by reinvestment of the economic rents generated by depletion [17, 18, 19, 2]—establishes only a negative result: under the specified conditions, WS cannot be achieved if reinvestment falls short [20, 21]. Furthermore, the rules and procedures for IW accounting, a process of reducing different kinds of capital to a common metric, are guided by economic reasoning but, as Asheim [22] demonstrated, ultimately are arbitrary in some respects, and therefore, non-unique (see also [23]).

Practical concerns with WS include unease with the maintained assumption that financial capital is and will continue to be readily substitutable for other kinds of capital, especially natural resources; maintained technological optimism; and insufficient attention to uncertainty. (i) Substitutability is a technical matter [24] and the WS assumption reflects technological optimism—the belief that scarcity is and will continue to be the mother of invention. (ii) Typically, WS formulations elide issues of technology, which augments production, and population, which increases demand, by noting that if productivity and population grow at the same rate, the algebra of WS works out [25]. (iii) While lack of clairvoyance is palpable in the WS discourse regarding, for example, future technology and the content of future consumption bundles, explicit modeling of uncertainty in future welfare is rare in the foundational literature. This perhaps reflects the origins of the WS discourse, which had its roots in concerns that people are inclined to be greedy, consuming more than is sustainable, thereby condemning distant future people to predictable hardship.

1.2.2. Strong Sustainability—Sustaining Particular Resources

The essence of SS is in sustaining resources that might be critical to humans thriving, economically, morally, and/or spiritually [26]. With this as its mandate, SS is broadly defined. Motivations may include:

- Sustaining the earnings humans can extract from nature as in the safe minimum standard of conservation, SMS [27, 28, 29, 30] and the safe operating space, SOS, concept that emerges from the planetary boundaries, PBs, literature [31, 32];
- Avoiding asymmetric risk, in some cases by taking pre-emptive action, as in the precautionary principle, PP [33, 34, 35, 36];
- Preserving nature for its amenity value to humans or for its own sake [37].

SS makes intuitive sense too, for resources that are in some way special: essential, i.e., non-substitutable in production; unique and highly valued, i.e., non-substitutable in consumption; and/or subject to asymmetric risks of, e.g., ecosystem collapse.

SS raises a considerable variety of issues, which can be summarized in two broad categories, both of which raise concerns about opportunity costs, i.e., the potential rewards foregone by insistence on SS constraints. SS will diminish welfare if (i) assumptions of non-substitutability in production and/or consumption turn out to have been too pessimistic, and/or (ii) future generations have a different view of what is unique and highly valued [38]. At the practical level, while even strong SS proponents such as Daly [35] agree that applying SS to all natural resources would be “absurdly strong sustainability” there is no broadly acceptable unique rule for bounding the set of resources and entities to which SS constraints should be applied. In the real world, uncertainties abound, which motivate SS but make its application more challenging. While SS is intended to draw a firm line in the sand, its application in an uncertain world needs to be flexible and open to revision in light of experience ([40].

1.2.3. Exhaustible and Renewable Resources

The distinction between exhaustible and renewable resources is significant to both the WS and SS discussions. Exhaustible resources cannot be replaced in kind, and recycling and exploration can extend the sustainability time-horizon, but not forever. WS into the distant future requires that substitutes in production and/or consumption be found. Renewable resources can regenerate under favorable conditions and the challenge is mostly to manage harvest and regeneration to meet sustainability goals. Yet, it is likely that sustainability in the large will ask more of renewable resources than just sustaining themselves: the ultimate limits on exhaustible resources suggest that renewables will need to compensate in some way for the depletion of exhaustibles. There is a folk theorem to the effect that WS can be assured if harvest of renewable resources can be expanded sustainably to compensate for depletion of exhaustible resources [41]. The implication is that SS might be motivated by concerns about exhaustible and/or renewable resources but, even when exhaustibles

provide the motivation, sustainability prescriptions frequently, perhaps typically, involve restraints on the depletion of exhaustibles and compensating enhancements of renewable resources.

1.2.4. WS-plus

The opportunity costs of SS are such that it is hard to imagine a viable sustainability policy that requires SS across the board. However, nagging concerns remain that, with even the most optimistic plausible assumptions about substitutability, certain resources truly are critical. Therefore, a sustainability criterion with pragmatic appeal to policy makers and practitioners is WS-plus [42, 43]: the intergenerational bequest should maintain non-diminishing IW while including adequate stocks of a few truly critical natural resources. This approach is broadly consistent with the axiological approach of [44] and the Brundtland Commission's observation: "At a minimum, sustainable development must not endanger the natural systems that support life on earth" [1, p. 42].

2. Materials and Methods

2.1. A Simple Model of a Stylized but Informative Case

Barfuss et al. [45], hereafter BDLK, offer a stylized model, which they motivate as not only simplifying but offering "a deeper understanding more complex models might miss" (p 2). My intention here is to introduce their model as an expositional tool, as its authors intended, and use it as a platform for thought experiments exploring the role of risk management tools in a reassessment of sustainability and safety paradigms. Then, I return to a more detailed treatment of the intergenerational commitment to sustainability.

BDLK postulate a renewable resource subject to a tipping point (RRTP)—a case of considerable interest to ecology and ecosystem management [46, 47]. In their model:

- There is a decision maker (the agent) who seeks a reward on behalf of a group of resource-dependent people. The reward could come in welfare as economists define it or, in more isolated circumstances, perhaps food to store for the winter.
- The resource is at any time in one of two possible states, **Prosperous** or **Degraded**. The agent chooses a level of exploitation—**High-pressure** exploitation generates greater rewards, but is possible only in the **P** state.
- In any period under **H**, there is a chance that the resource collapses, i.e., tips to the **D** state where exploitation yields zero reward.
- Under **Low-pressure** exploitation in state **P**, the reward is smaller, but there is no chance of resource collapse.
- In state **D**, exploitation is impossible, but there is a chance that the resource will revert to the **P** state.

BDLK consider three paradigms for managing the resource:

- **Optimality, O**, in which the expected present value of the time-stream of rewards is maximized;
- **Sustainability, S**, in which the expected present value of the time-stream of rewards is maintained $\geq PV(r^{\min})$;
- **Safety, Sa**, which avoids all risk by maintaining the cautious **L** policy at all times, so that reward never falls below r^l .

System states, s : Prosperous or Degraded

Policies, π , are **risky** (High-pressure exploitation if **P**; zero if **D**) and **cautious** (Low-pressure always).

Key variables

r^h	Time-stream of rewards from H action in P state (zero in D state).
r^l	Time-stream of rewards from L action in P state (zero in D state).
r^{min}	The minimum acceptable time-stream of rewards.
t	A time period in $(0, \dots, T)$, such that r_t, π_t and s_t are r, π and s , respectively, in period t .
d	Probability of collapse from H action in P state in a given period (i.e., a measure of system vulnerability).
p	Probability of recovery in D state in a given period (i.e., a measure of system resilience).
δ	Discount factor expressing the agent's time preference, $0 \leq \delta \leq 1$; future rewards are discounted entirely at 0, while there is no discounting at 1.
$E(PV(r))$	Expected present value of the time-stream of rewards.

They conclude, as announced in their title, that **O** guarantees neither **S** nor **Sa**, and that “the sweet spot” is the set of solutions **OSSa** that satisfy all three paradigms.

2.1.1. How Does This Model Relate to the Standard Sustainability Concepts?

Because the objective is reward to humans, the **S** criterion resembles **WS** in at least that respect. On the other hand, **WS** permits the destruction of a particular resource if future welfare nevertheless can be sustained, a situation not addressed by these authors. Early **WS** formulations addressed exhaustible resources, and sustainability prescriptions focused on disciplining human impatience and greed rather than managing risk [19, 2]. For **BDLK**, the focus is on managing a renewable resource that responds to exploitation with stochastic collapse and recovery.

Sa obviously bears a relationship to **SS** in that it would preserve the resource in the **P** state. Like the **SMS**, it is targeted at conserving the resource but motivated by ensuring a continuing stream of rewards for people. Like an inflexible **PP**, it avoids all risk of collapse, sometimes at substantial opportunity cost. **BDLK** associate **Sa** with **SOS**, the safe operating space as defined in the **PBs** literature.

The set of outcomes that are both **S** and **Sa** is interpreted as **SAJOS**, the safe and just operating space [48]. However, while there is a strong normative case for including sustainability among the criteria, the **SAJOS** concept of justice goes far beyond **S**.

2.1.2. How General Is This Model?

RRTP is a special case among sustainability problems, but nevertheless, a case of substantial and increasing interest. A little introspection suggests that the model can be applied, with appropriate modification, to a broader range of sustainability issues. It would accommodate the case of an exhaustible resource with uncertain reserves quite readily—reserves might be exhausted with probability d and exploration might augment them with probability p —and, with a little more gymnastics, could address the case where there is a d chance of resource exhaustion and a p probability of discovering a technology that enables the substitution of more plentiful resources. It might be objected that resource exhaustion is seldom an all-or-none process in a given time-period—and d could be expressed as a probability distribution to resolve that issue—but discoveries, whether of new resource deposits or new technologies, tend to be discrete but uncertain events.

The unit of analysis could be a firm, a local or regional forest or fishery, or planet Earth; the agent could be a farmer, forester or fisher, a forest or fishery manager, or a benevolent global manager; the beneficiaries of paradigm and policy are human always, but could be a farm family, a resource-dependent community, a regional or national citizenry, or humanity as a whole; and the reward could be denominated in monetary terms as appropriate for a sophisticated economy or in physical units of product as might be appropriate for an isolated subsistence firm or community. There is more than

a hint that the authors believe their conclusions apply across this broad range of scales: “Our model is deliberately stylized, thereby applicable across multiple cases and scales” [45, p. 2].

The intergenerational setting of many WS formulations is missing, replaced by an agent serving stakeholders, and all parties, implicitly, are very long-lived.

The BDLK model is not presented as a decision tool for managers and policy makers—rather, it is intended to clarify sustainability issues and concepts and communicate them simply to non-specialist readers. For that reason, they do not address issues of model specification, parameterization, calibration, and validation. They assume implicitly that the model contains everything the agent needs to know, and the agent knows it all. This is fine for their purposes, conceptual analysis and communication, but does not address the concerns of Brock and Tan [40], who address the roles of science and optimization methods in policy and management for a very uncertain and sketchily understood world.

2.2. Thought Experiments to Elucidate the Implications, Bound the Scope, and Test the Generality of the Simple Model

To dig a little deeper into the implications of the simple model, consider the following thought experiment. First, set $\delta = 1$, i.e., the agent has neutral time-preference, because we know already that positive time-preference undermines intergenerational equity and ultimately, sustainability itself [49]. Note that Asheim et al. endorse discounting future prospects but only as much as would be required for intergenerational equity, because the present generation consumes too little unless it discounts for expected increases in productivity over time (see also [50]). Potential changes in productivity are not addressed in the BDLK model.

Then, set r^{\min} at the subsistence level, in order to focus on conditions under which a failure of sustainability would threaten human survival. With these settings, examine the effects of varying r^l , r^h , d , and p . Beginning with this simple structure, I reconsider the role of safety given a sustainability constraint; examine the impact of scale on sustainability prospects; elaborate on the intergenerational commitment; introduce uncertain welfare and consider its implications for sustainability; and explore some interactions between intergenerational and intragenerational equity concerns.

3. Results

3.1. The Role of Safety in the BDLK Model

First, observe that all of the variables in play— r^l , r^h , d , and p —influence $E(PV(r))$, which matters for optimality and sustainability, but the reward for safety (which requires the **L** action whenever a chance of harm is present, i.e., whenever $d > 0$ and $p < 1$) is influenced only by r^l . BDLK’s “sweet spot” is **OSSa**, the set of solutions that satisfy all three criteria—optimality (**O**), sustainability (**S**), and safety (**Sa**).

I argue that, in this stylized context, **O** is always good, but it is not good enough if it is unsustainable. More formally, the intergenerational commitment requires non-diminishing IW. Therefore, the question is whether **O** should be constrained by **S**, **Sa**, or both. **Sa** in effect sets reward at r^l forever, eliminating opportunity for greater reward as a direct consequence of eliminating risk. If the reward given the **L** action is $r^l \gg r^{\min}$, **OSSa** promises a future where people live well and risk-free. However, this outcome is plausible only in circumstances so well-endowed that living is good even under the cautious policy—it is good to be born rich! If r^l is little more than r^{\min} , mere subsistence, the cautious policy holds the human beneficiaries in a poverty trap, and the **H** action may be a tempting gamble. Even worse, if $r^l < r^{\min}$, the situation is safe but unsustainable. With low r^l , **Sa** promises bare subsistence or worse.

Constraining **O** by **S** provides sustainability by insisting that $E(PV(r)) \geq r^{\min}$. Together, **OS** maximizes $E(PV(r))$ subject to $E(PV(r)) \geq r^{\min}$, which is all the society needs in the way of sustainability given the BDLK formulation and my thought experiment settings. We need to dig a little deeper to find cases where anything is gained by adding a **Sa** constraint to **OS** when time-preference is neutral. Here, I address two issues submerged just beneath the surface in the BDLK analysis: the reliance on

an implicit risk management strategy—savings to cushion collapse of the resource—that underpins their **S** paradigm; and the issue of scale, which I argue is central to the justification or otherwise for adopting the **Sa** paradigm in a particular case.

3.1.1. Risk Management

Observe immediately that collapse and recovery are stochastic, and $E(PV(r))$, the expected present value of the time-stream of rewards, plays a major role in the optimality and sustainability criteria. This has important implications. First, $E(PV(r))$ has the virtue of focusing the agent on a time-stream of future rewards. The discount factor, $0 \leq \delta \leq 1$, expresses the agent's time preference—when $\delta = 1$ time-preference is neutral, i.e., the agent does not discount future rewards. The safety criterion makes no reference to time-preference, but it is effectively neutral—safety forever would sustain reward r^l forever.

Second, with imperfect foresight, future rewards obviously are expectations in vernacular terms—what we anticipate as opposed to what we eventually realize. However, expected value has rigorous meaning in statistics, i.e., the probability-weighted average of all the possible values of future rewards. To optimize and/or sustain expected value of rewards implies risk-neutrality—indifference between an outcome x for sure and a bet with a range of possible outcomes having a probability-weighted average of x —and certainty-equivalence given repeated trials and deep pockets. Suppose that in period t , the system collapses and r_t falls to zero. If current period consumption is limited to current period rewards, the society perishes in period t . It follows that $E(PV(r))$ is meaningful for optimality and sustainability only if mechanisms exist to maintain consumption should the system collapse. Implicit in the model, the **O** and **S** paradigms use savings for risk management. Optimizing or sustaining, as the case may be, $E(PV(r))$ is effective in the long run only if consumption is limited to $E(r_t)$ in each period. Therefore, if the **H** policy is in effect, rewards are $r_t^h \geq E(r_t) \geq r_t^{\min}$ —otherwise, the society is bound to perish—and savings are $r_t^h - E(r_t)$ in each period until a collapse occurs. At that point, a society with accumulated savings of $n \cdot r_t^{\min}$ can tighten its belt and survive n consecutive periods without recovery.

More generally, **O** and **S** as defined here are predicated implicitly on adequate and successful risk management. Risk management provides several mechanisms [51] including:

- Self-protection, i.e., expenditure of effort and resources to reduce the chance of harm by reducing d , and/or increasing p ;
- Self-insurance, which may include savings to help maintain consumption $\geq r_t^{\min}$ in all periods, even if r_t falls below r_t^{\min} , and diversification to reduce dependence on a single vulnerable resource;
- Purchased insurance, i.e., a contract that promises compensation in the event of specified harms.

In the real world, some risk exposure usually remains. In our simple case, there are two obvious possibilities. (i) Risks may extend beyond simple stochasticity, to include asymmetric risk, ambiguity, and/or unknown unknowns, in which case, risk neutrality is a hazardous stance [52, 53]. (ii) Even with simple stochasticity, the BDLK model assumes certainty-equivalence, which requires many trials and deep-enough pockets. These caveats may be upended by a run of bad luck—in the simple case, a too long sequence of failures to recover. To summarize, certainty-equivalence is an attribute of the BDLK model but not necessarily the real world. Invoking the real world introduces additional categories of uncertainty: e.g., model specification uncertainty and parameter uncertainty, which unravel the BDLK implicit assumption that the world, the model, and the agent are all on the same page, and motivate questions about the roles of optimization, planning, and adaptive management in policy and management [40]. Where risk management falls seriously short of certainty-equivalence—i.e., when the threat of harm is inordinate to the potential benefit—there may be a case for a **Sa** constraint. Three elements to assessing whether a particular risk reaches the threshold for

invoking a safety remedy have been suggested [33]—the evidence of threat, the magnitude of worst-case harm, and the expected efficacy of the best available remedy.

3.1.2. Scale: Within Limits, Increasing Scale Weakens the Case for Safety

BDLK suggest that their reasoning and their case for **S** and **Sa** rules are applicable at any scale. To the contrary, I shall argue scale matters in theory and empirically. Moreover, increasing scale tends, if anything, to reduce the need for **Sa**, and we have seen that **Sa** often entails a non-trivial opportunity cost. Scale, in this discussion, has at least three dimensions: size in terms of geographic area; diversity of natural, built, and human capital; and complexity of organization. A fourth dimension—openness to trade in raw materials, goods and services, and mobility of capital and people—substitutes for scale in that it allows smaller jurisdictions to enjoy many of the benefits of scale.

All four dimensions of increasing scale tend to reduce sustainability risk. (i) Larger geographic scale increases the likelihood of greater diversity in resources and human capital. For one simple example, increasing diversity in weather-related exposure reduces overall risk. (ii) A society that is more diverse in natural resources, human and social capital, and product mix has greater ability to manage risks internally—including the ability to cushion harmful outcomes for particular subregions, firms, and people—which encourages specialization and increases welfare. (iii) Increasing complexity encourages emergent responses to challenging conditions and is likely to increase resilience. (iv) Relatively open borders increase scale, dramatically for small nations and regions, by permitting jurisdictions of a given size to operate at a larger scale via trade in raw materials, goods and services; cross-jurisdictional investing and borrowing; and relatively unrestricted movement of people across jurisdictional boundaries.

Larger scale enhances specialization both within a jurisdiction and, given relatively open borders, among jurisdictions, thereby increasing the level of welfare that is sustainable. In terms of risk management, larger scale increases opportunities for diversification, facilitates stronger savings and credit markets, and increases the feasibility of transfers of money and resources to regions stricken by natural disasters. More generally, increasing scale weakens the case for safety at every level. For the farm, forest, or fishery, the need for safety is diminished when society is sufficiently large and diverse to cushion failures in individual resources, firms, and sectors. For society, there is less need for safety when similar resources elsewhere may substitute for critical domestic resources.

The limits suggested in the subheading are of at least two kinds. First, planetary boundaries, PBs, suggest inflexible constraints at the global level. However, that is far from the whole story—it is important to recognize the substantial opportunities for risk management and internal adjustments within the global community [54]. A similar point has been made about global hunger [55]: solutions are not so much about increasing total food production as about needed reorganization throughout the world food system. Second, global willingness to maintain openness to trade and migration matters. Retreat by nations and regions from open-border policies would reduce global capacity to cushion regional and local populations suffering localized resource crises.

In summary, increasing scale tends to reduce the need for the **Sa** paradigm and increase the viability of the **S** paradigm as a sustainability constraint in **OS**. Given that **S** resembles weak sustainability, it is important to note that increasing scale does not diminish the role of **S** or **WS** for a jurisdiction that aspires to thrive by (among other things) importing critical resources, because such a strategy works only for jurisdictions that can afford to pay for them. There may well remain a role for **Sa**, and its near-analogs strong sustainability, the safe minimum standard of conservation, and the precautionary principle. **Sa** might be invoked to address critical raw materials at the global level, or those that are nationally critical in the event of global retreat from trade-friendly policies; to preserve iconic natural entities; and to avoid or mitigate inordinate risks.

3.2. *The Intergenerational Commitment with Uncertain Welfare*

The intergenerational commitment obligates each generation in its turn to bequeath to the next an undiminished opportunity to meet its own needs, i.e., non-decreasing welfare opportunities or,

equivalently, non-diminished IW. The present generation has, by virtue of its presence, the circumstantial power to consume and destroy, and to save, conserve, invest, and build, thus, influencing the prospects of future generations for good or ill. That is, each generation has the power to increase its own welfare by reducing its bequest of IW. This fact lies at the core of the sustainability question, which can be framed as how, and how much, should we restrain and redirect our exercise of our circumstantial power in order to sustain future prospects? Furthermore, the sustainability question is inherently an ethical question. What if any moral authority does a transitory generation enjoy, by virtue of its presence, to act in ways that diminish the prospects of future generations [56] or, conversely, what if any moral obligations limit a transitory generation's exercise of the power conferred by its presence?

3.2.1. The Illegitimacy of Generational Greed

A major contingency faced by future generations is whether they will exist and have the resources to thrive, and we who presently exist have non-trivial power over that. Our power over the future is asymmetric but only circumstantial, which provides a weak thread on which to hang a claim of moral priority over future generations. It follows that our presence gives us transitory power over the future, but that is a matter more of fact than of value and in no way undermines our obligation to the future.

It might be objected that "all (human) lives are precious" endows the present with moral authority, i.e., the fact that we are here and the belief that our lives are precious might endow us with legitimacy, for example, to take care of ourselves first. "All lives are precious" is a non-trivial moral claim—many would elevate it to the status of a principle—and it suggests a justification for self-preservation. However, it implies that future lives also matter, even contingent future lives, and their self-preservation is justified in their turn. Parfit's non-identity problem [56]—that the commitment to future generations might be undermined by concerns that they might be unlike us, perhaps culturally—is also about how we use the circumstantial power conferred by our presence, and provides no moral foundation for stinting on the intergenerational commitment.

What, then, are our obligations to provide opportunity for future generations? Perhaps self-preservation of future generations is justified only to the extent allowed by whatever bequest they receive from their forebears (a luck of the draw sort of thing)? We can dismiss this claim on ethical grounds because their inheritance is not entirely a matter of luck, in that the present generation has the power, but not the ethical mandate, to decide self-servingly to stint on the bequest provided. The fact that future generations are contingent in several dimensions does not undermine the intergenerational commitment—instead, I would argue, it enhances its salience.

3.2.2. Uncertain Welfare

Suppose welfare in each period, w_t , is stochastic with non-decreasing $E(w)$. Then, some generations will experience more welfare than $E(w)$ and some will experience less. If the question of survival arises in the case of an unlucky generation, (how) might the intergenerational commitment be modified? First, consider generational self-interest. The more tenuous the prospects facing a generation, the stronger is its case for prioritizing its survival above its bequest. All subsequent potential generations also have a self-interest in the survival of an embattled present generation, because the first generation to perish ends the game for all subsequent generations.

Now, consider the import of the intergenerational commitment. A bedrock principle is that each generation is valued, even if it turns out to be the last. We can say this much without triggering any concerns regarding interpersonal comparison of utilities. If generations are defined in binary terms—the generation exists in its turn, or it does not—no comparison of utilities is involved, because each additional generation is added at the end of the existing sequence. It is only if we argue that generations per se do not matter—what matters are people and their welfare—that Rawls' difficult questions arise [57] along the lines of: How should fewer generations living well, or generations of fewer people living well, be valued relative to more generations, or generations with more people, living more precariously?

Therefore, each additional generation is valued, and with neutral time-preference, more generations are preferred to fewer. If w_t approaches the subsistence level, the unlucky generation in t is not merely justified in tending to its own survival first: its obligation to future generations is to survive if at all possible, because if it fails, the game ends there. More generally, suppose that bequeathing a little less to the next generation would materially increase a generation's chances of surviving and producing a successor generation. Is this—an increase in generational self-protection at the expense of bequest—a chance that a penurious generation should take? It is tempting to postulate that intergenerational equity would be attained if each generation had an equal chance of survival—and that is surely plausible if the game starts anew with each generation. Yet, to the contrary, the first generation to perish ends the game for all subsequent generations. Therefore, the ethical argument tilts strongly toward survival of each generation in its turn. However, a generation's decision to increase its chances of survival entails potential costs and potential benefits in terms of viability and welfare for subsequent generations. Therefore, a generation's moral authority to pursue its own survival is not unlimited.

A commonsense general form of the sustainability commitment in an uncertain world is that each generation in its turn is obligated to make a good-faith effort to endow the next generation with non-diminishing IW. Why a good-faith effort? In a certain world, there would be no need to deviate from an absolute obligation. However, in an uncertain world, a generation may be forced to choose between an undiminished bequest and its own survival. The good-faith caveat provides guidance in making that choice. A good-faith bequest from an unlucky generation may be smaller than the non-diminishing $E(w)$ benchmark, if justified by increased chances of generational survival and evidence of moral consideration of the trade-offs involved. The good-faith caveat has relevance for lucky generations, too. Their good fortune brings them more than $E(w)$ and their survival is not at issue, so they have an obligation to use at least a part of the excess, i.e., a part of $w_t - E(w_t)$, to increase their bequest to help get future generations back on to the non-decreasing $E(w)$ path.

3.3. What Can We Learn from the BDLK Model *re* Intergenerational Obligations?

In the BDLK model, uncertainty is at the core of the sustainability question—not a tweak that can be added at the cost of additional complication—so I consider the implications of extending the model to the intergenerational context. The BDLK world already has stochasticity when $d > 0$ and $p < 1$; we could add more uncertainty in several ways, e.g., by making the parameter values d and p uncertain, by making rewards stochastic such that $E(r^h) = r^h$ and $E(r^l) = r^l$, and by leaving the agent to discover these values by trial and error. The BDLK world does not have explicit generations, nor does that world have explicit savings, yet savings are essential if $E(PV(r))$ is to play a decisive role in policy choice. Therefore, I consider the implications of introducing distinct generations and savings explicitly.

3.3.1. Generations

If a single time-period t represents a generation, BDLK's future-regarding framework would be undermined. Given **S**, **Sa** would have strong appeal to the self-interest of the present generation because they would have no opportunity to recover from a collapse, and potential future generations would agree because it would improve their chances of existing. A more interesting formulation would define a generation as lasting for multiple but not unlimited time-periods. This would motivate future-regarding behavior in the present generation. In the BDLK model, concern for the distant future can be motivated by assuming a very long-lived agent with neutral time preference. With explicit generations, we can invoke the intergenerational commitment to sustainability.

3.3.2. Savings

We have seen that in the BDLK model, the **O** and **S** paradigms implicitly use savings for risk management. If the **H** policy is in effect, rewards in t are r^h where $E(r^h) \geq E(r_t) \geq r^{min}$ —otherwise, the

society is bound to perish—and $r^t - E(r_t)$ is added to savings in each period until a collapse occurs. If at any time, the resource is in the **D** state, savings are exhausted and the draw from the p distribution is no-recovery, the game is over for the present and potential future generations.

How do savings relate to the good-faith bequest? In the BDLK “sweet spot”, an ideal time trajectory of outcomes is one in which the resource is maintained in the **P** state forever. This surely suggests that if distinct generations had been modeled, the undiminished intergenerational bequest would be **P** always (see also [58]). However, with my amendments to their framework—the multi-period lifespan of each generation and the explicit role of savings, given the stochasticity of the system—the opportunity cost of **Sa** suggests the possibility that the resource might be bequeathed in the **D** state. A generation receiving the resource in the **D** state and carryover savings of at least r^{min} will be able continue the game for at least one more period, whereas a bequest of $n \cdot r^{min}$ in savings would support n more periods of frugal living in the absence of recovery. Therefore, the value of the bequest is not all about the condition of the resource. Accumulated savings matter, too.

Each generation is managing the resource and savings for itself and the future. The **H** policy provides a chance of higher reward that can be used for consumption and/or to build savings. The amount of savings in hand at the beginning of a period is an important consideration in deciding policy—with substantial savings, the penalty for collapse is less daunting, which makes the **H** policy more attractive. Because BDLK did not explore the implications of scale, there remains a relatively big role for the **Sa** paradigm, as befits an isolated society dependent on a single resource. Nevertheless, explicit consideration of savings makes a difference: the need for **Sa** is reduced when the accumulation of savings is larger.

What is the good-faith non-diminishing bequest in a BDLK world with stochasticity, savings, and distinct generations with multi-period lifespans? We know that certainty-equivalence alone is not good enough when survival is at stake, and savings are essential to maintain consumption in the event of ecosystem collapse. Yet, without additional value-assumptions addressing risk-attitudes, we cannot know the rate at which savings compensate for the degraded condition of the resource. We are left with only some rough guidelines: accumulated savings and the condition of the resource both count in evaluating a bequest; a hard-luck generation should be given some leeway to enhance its survival prospects; and a fortunate generation has a good-faith obligation to increase its bequest as well as its consumption.

To this point, the discussion has emphasized the role of savings in cushioning welfare shocks, which raises a fair question—what about borrowing? With increasing scale, a broader range of horizontal financial transactions becomes feasible, including borrowing from regions and sectors not so hard-hit, and inter-regional and/or intersectoral transfers such as disaster relief. In reality, several generations populate the world at any given time, which permits vertical borrowing and gifting. For example, the young need working capital and may receive gifts and/or loans from their elders, and the elders eventually will need care provided by the young. Overlapping generation models more nearly capture the scope of intergenerational transactions and transfers [59], but I do not pursue that avenue here.

3.4. Generalizing Beyond the BDLK Model

With increasing scale come many or all of the following—greater geographic area and variety of natural resources, larger and more diverse human populations, more complex economies and societies, and greater openness to trade of raw materials, goods and services, financial and human capital. Other things equal, increasing scale reduces the need for **Sa**, for reasons already familiar.

The thought-experiments with the BDLK model have revealed the inherent difficulty of specifying the non-diminishing bequest when it has two quite different components. In the real world, the intergenerational bequest has several categories of components—natural capital, built and manufactured capital, savings net of depreciation, human capital, social capital, and political capital—each of which is really a vast collection of things that are not quite comparable without invoking rules for comparing. Unfortunately, the standard WS theorems cannot be generalized to

cases with multiple categories of capital [22], leaving us to formulate, construct, evaluate, and implement IW accounting rules that are condemned to remain arbitrary to some degree.

The weak sustainability concept of inclusive wealth is a well-known example of a conceptual accounting system for comparing and aggregating different kinds of capital, and the adjusted net savings (ANS) and inclusive wealth (IW) accounts developed by the World Bank and UNEP—which began with a core group of countries in 1970 and now are published annually for more than 200 countries—are well-known and well-regarded applications. Yet, the IW accounts are not uncontroversial. They have conceptual limitations consistent with those of mainstream welfare economics—primarily the influence of ability to pay on value—and limitations that reflect incomplete and, in some cases, unobservable data. Examples of the latter include: economic values for environmental damage, which still tend to be implausibly small despite improvements in data and methods over the years; and human, social, and political capital, which are not observable directly, but calculated indirectly from the unexplained residual in estimated equations relating output to measurable inputs. Nevertheless, ANS and IW are among the most credible attempts at measuring and monitoring the evolving sustainability status of most of the world’s countries.

The need for *Sa* is reduced in BDLK models when savings and intergenerational bequests are considered, and the role of safety in more general models is reduced at larger scales. Nevertheless, there remains a role for safety policies in support of *WS*, i.e., what we have called *WS-plus*, where *WS* is supported by *SS* provisions to protect critical resources and iconic natural entities, and to avoid inordinate risks.

3.5. Intragenerational Burden-Sharing When Welfare Prospects Are Distributed Unevenly

To this point the discussion has assumed homogeneity and commonality of interest within generations. To expand the dimensions of ethical sustainability policy, consider the case where these assumptions are challenged.

3.5.1. On Heterogeneous Prospects

Our generation includes rich and poor households, regions, and nations. In this context, “all lives are precious” has clear moral implications beyond self-preservation. At the very least, the well-off are morally obligated to avoid conscious acts that reduce the welfare of the badly-off [60]. Among the implications is compensation for poor people who are asked to bear burdens in service of sustainability that benefits a broader population. Furthermore, it is argued frequently that the well-off are obligated to maintain a safety net, i.e., provide decently for those unable to care for themselves. In addition, perhaps, the well-off are obligated to improve the prospects of the badly-off when feasible and, ideally, the increment would take the form of investments expected to deliver a long time-stream of welfare improvements.

3.5.2. On Commonality of Interests.

Many well-off people living in temperate zone conurbations are deeply concerned about the need to conserve critical natural capital, and perhaps treasured tracts of nature, for the future. Globally, land-clearing and cropping for export, as well as to meet local needs, have resulted in continuing losses of wildlife habitat, while wildlife populations have diminished by 60 per cent between 1970 and 2014 [61]. Wilson [62] has argued that “nature needs half”, i.e., fifty percent of the earth’s land surface should be conserved or restored as necessary, to serve the needs of nature. Much of the critical and threatened natural capital is located in lower-income regions, where it provides sustenance for local residents. This suggests a conflict of interests, but arrangements leading to mutual gains may be feasible.

3.5.3. On the Intersection of These Concerns

As it happens, many of the richest tracts of nature and many of the poorest people are co-located in the tropics, which implies serious conflict of interest between relatively well-off temperate zone

people and poor tropical residents earning meager livings from the bounty of nature. Now, we have a moral case for (over-)compensation of poor tropical residents asked to bear the burden of conserving critical natural capital for the future, and a practical case for incentivizing these people to perform the desired conservation.

To elaborate a little, suppose that our generation includes rich and poor, and our resources include IW and nature; and that the future will also need IW and at least some nature. Some groups of poor people have, by virtue of their location and history, effective control of abundant stocks of nature that the world needs now and in the future, and it commonly is proposed that they restrain their exploitation thereof in order to endow the future. Insistence that these people bear the burden of restraint may impose intragenerational unfairness in pursuit of intergenerational fairness.

Farmer and Randall suggest three principles to guide resolution of these kinds of conflicts [27]:

- 1) The existence and prospects of present humans are valued.
- 2) The existence and prospects of future humans are valued.
- 3) Moral agents have intragenerational obligations to each other, such that commitments to provide opportunities for the future must be negotiated in the context of intragenerational obligations to each other, here and now.

How might these principles be applied, and what difficulties might arise in application? Imagine a well-funded global conservation authority: a “Common Heritage Fund” taxing world trade at 1% would generate revenues sufficient to fund the preservation of substantial portions of the world’s unique ecoregions [63]. Such a fund makes sense for reasons of ability and fairness: local people often lack the capacity and political/governance capital to solve the problem and, in any event, they may not be the ones responsible for creating the problem ([64]. How might the authority set conservation priorities? Armstrong [65] points out that it is important to be clear about whether a conservation/restoration proposal seeks first and foremost to defend the intrinsic value of nature, or the nature-related interests of humans. In practice, these two priorities often point in different directions regarding the location and size of tracts to be protected.

Given that restoration and conservation are both costly activities aimed at augmenting and securing environmental services by maintaining and increasing the stock of natural assets, it is important also to consider the complementarities and trade-offs among prospective restoration and conservation projects.

If the motivations are mostly instrumental and prudential, as implied by the notion of natural capital, it makes sense to consider the potential benefits and costs. Often, both of these considerations—substantial benefits and relatively modest costs—point in the same direction to particular tracts, many of them tropical, in the less developed world. Yet, tilting the burden of conservation toward the tropics would severely constrain the options open to the poor—who are, as it happens, least responsible for the massive loss of biodiversity [64]. Fairness would require compensation for loss of income, which does not seem too difficult; for loss of autonomy, which may be harder; and for relocation of people, and perhaps communities, which would be still more difficult. The form of compensation really matters—ideally, it should provide a foundation for steadily increasing autonomy, social cohesion, and welfare over time.

The obligations of temperate zone populations do not end with subsidizing conservation in the tropics. Temperate zone ecosystems are valuable, too, and often degraded, which raises issues of restoration as well as conservation. Wilson [62] argues for a patchwork of strongly protected areas including all of the main distinctive ecoregions of the world. There is an overwhelming case for including viable tracts of the temperate and polar zones in the nature conservation portfolio, despite the higher costs. Most of the issues in prioritization apply here, too, including fairness to those of whom we demand the greatest adjustments.

3.5.4. Some Tentative Steps toward Win-Win Solutions

A considerable variety of governments, NGOs, and international authorities have been developing and field-testing policy instruments designed to incentivize and compensate local and regional resource-dependent populations to protect, restore if necessary, and preserve tracts of nature. Many of these instruments involve payments for ecosystem services (PES) where payment, ideally, is predicated on achieved and observable enhancements in environmental services. The basic idea of payments that incentivize socially beneficial behavior while compensating for lost income from resource exploitation is sound, and policies to implement it have potential. However, the success of PES programs and projects to date has been limited for several reasons [66]: they tend to cover relatively small areas, coordination across projects is limited, incentives often are insufficient, and monitoring the achievements of participants is often suboptimal because effort is more readily observable than performance. The REDD+ program (reducing emissions from deforestation and forest degradation) is global in scope and is incentivized by payments for results. It emerged from the Kyoto Agreement on climate change and is aimed at reducing emissions of atmospheric carbon. It, too, has had its successes, but these have been limited by perhaps excessive bureaucracy as well as the standard PES issues of insufficient incentives and difficulties in monitoring performance [67].

3.5.5. Sustainable Development Goals, SDGs

To this point, I have made no mention of sustainable development goals, which have been promulgated by the United Nations [69], various NGOs and some national and regional governments. For those who tend instinctively to situate sustainability within the WS and SS frameworks [44, 68], the SDGs are a little disorienting because, while they include goals consistent with WS and SS, they also include goals such as reduced inequalities, gender equality, and competent and responsive governance that are worthy in their own merits but do not seem directly related to sustainability [70]. Perhaps this reflects strategic attempts to broaden the coalition supporting sustainability by attracting people who are motivated primarily by those additional goals. However, I think there is a more compelling answer. Consider the goal of reducing inequality. There is evidence that inequality, at both the national and global levels, plays an important role in driving global biodiversity loss ([71, 72]. This provides a pragmatic reason for proactive relief of the poverty that motivates excessive exploitation of nature. However, Principle 3 situates this pragmatic concern within a broader ethical framework—progress toward intergenerational equity is more likely and its ethical foundations are more coherent when it is linked explicitly with progress toward resolving intragenerational fairness issues. By this reasoning, the pursuit of global justice and the conservation of the natural environment ought to be closely connected goals.

4. Discussion

Sustainability is framed here so as to honor its essential forever context—“... without compromising the ability of future generations to meet their own needs” [1] —that is, as an intergenerational commitment. The weak sustainability, WS, concept is very much in the Brundtland tradition, emphasizing intergenerational bequests of non-diminishing inclusive wealth, IW. The essence of strong sustainability, SS, is in sustaining resources that might be critical to human thriving, economically, morally, and/or spiritually. That is, SS is a concession to the fear that the composition of the bequest, which is a concern not taken seriously in WS so long as the value of the bequest is non-diminishing, really matters [26]. WS-plus—a commitment to include a specified set of critical natural resources within the IW package—is WS with a modest concession to the SS motivations. Fundamental to sustainability is the sequential nature the bequest, i.e., keeping the commitment generation after generation.

The BDLK model is introduced because it addresses an important case, a renewable resource subject to a tipping point, is positionally simple and fruitful, and its authors make a sweeping claim—the ideal policy is optimal, sustainable, and safe—that requires further examination. My enquiry reveals that (i) safety may have a high opportunity cost and, in cases where the safe policy yields rewards that are little greater than subsistence, may hold the resource-dependent society in a poverty trap; (ii) in a BDLK world, where it is the expected present value of a stream of future rewards

that is sustained, savings are essential to maintain consumption if the resource collapses; and (iii) scale really matters to sustainability because it enriches opportunities for risk management. The normative domains of sustainability and safety are quite distinct—sustainability always, but safety only when really needed, e.g., to avoid inordinate risks.

The intergenerational bequest is only implicit in the BDLK model, since it abstracts from generations, but the implicit bequest is simple—pass on the resource in the **P** (prosperous) state. Yet, given the introduction of savings, and of explicit generations, the composition of the bequest becomes an issue—how should we assess the value of a bequest consisting of a resource-state and some accumulated savings? This turns out to be an instance of the more general problem of evaluating a bequest consisting of different kinds of capital: it is impossible to generalize Hartwick-type WS theorems when multiple kinds of capital are involved [22]. Nevertheless, the concept of non-diminishing IW is so compelling that it makes sense to continue improving the IW accounting rules, even when we concede that the last vestiges of arbitrariness are unlikely to be eliminated.

Finally, intergenerational commitments in the real world must be negotiated in the context of intragenerational obligations to each other in the here and now, which suggests that intragenerational fairness is an essential component of policy to promote sustainability and helps explain the inclusion of equity in various dimensions among the sustainable development goals.

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