Forecasting Trajectories of Fabricated and Natural Capital: A Political Economic Model of Doomsday, Social-ecological Resilience and Green Innovation

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Abstract
An instructive graphical macroeconomic theory is recapitulated describing the interaction of private production of commercial services with natural production of ecosystem services. It features investments in maintaining the health of natural capital and analysis of marginal changes in absolute metrics of private and natural capital productivity. Analysis of trade-offs among costs, benefits and wealth production explore macroeconomic trajectories employing sustained yield doctrine, low-impact technologies, green technologies, artificial production of ecosystem services, debt-financed natural capital investments and a more probable scenario. Sustained yield won't work as a policy or prescriptive framework. Widespread restoration of robust ecosystems is unlikely, but resilient natural capital systems may be possible. Large investments in natural capital restoration and low-impact green technologies are required while retaining reasonable levels of profitability in both the commercial and ecosystem restoration sectors. The role of projected innovation in achieving long-term sustainability and climate stability is projected and unresolved issues identified.
Keywords:
Social collapse, Alternative futures, Sustainable development, Ecosystem investment, Political economics, Green technology

1. Introduction

The Model of Macroeconomic Real Values (MMERV) is an instructive graphical theory (Figure 1). It offers a formal and more rigorous approach to broad problems of ecological economics than prevailing conceptual argumentation. It also posits that avoiding collapse is now a major problem for all macroeconomic theory and research. The MMERV visually describes trajectories of economic behavior in logical time driven by how nations or planets might cope with the conflicts between private capital production versus that from 'free' self-organizing forms of public capital. The latter might be climate systems, ecosystems, or other forms of evolved and resilient cultural or institutional systems. These trajectories might be sustainable and a few simplified scenarios are explored through MMERV graphs. Basic 'free and natural' macroeconomic behaviors are considered first followed by more policy-driven prescriptive options and long-term macroeconomic trajectories. The component curves of the basic MMERV and how they relate to each other are as follows.

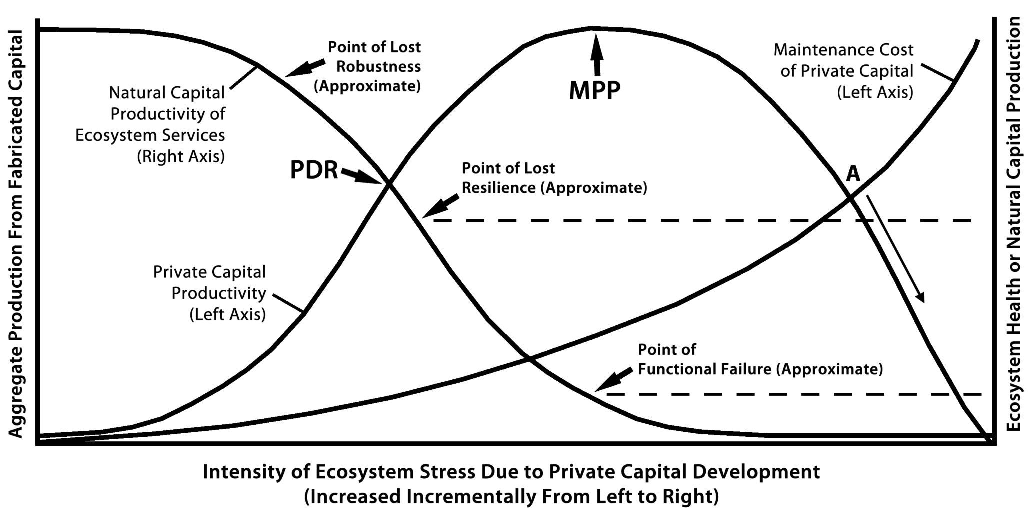

Figure 1. Graphical exposition of the basic Macroeconomic Model of Real Values

1.1 Natural capital production

The downward curve all the way across Figure 1 tracks the health of dynamic natural capital systems as it is increasingly stressed by growing and intensifying private capital deployments over time (Davies and Jackson, 2006). The levels of ecosystems' health along this curve can be understood as levels of natural capital wealth by virtue of the production of ecosystem services, that begins at its maximum potential level prior to any stresses at the left edge of Figure 1. These systems' robustness allows their functional health to decline slowly upon initial stresses. A tipping point of lost robustness is passed as further stresses compromise ecosystems' adaptive and regenerative capacities and natural capital wealth then declines rapidly. At another tipping point, as these loses decline most rapidly, aggregate natural capital systems loose their resilience in sustaining ecosystem services under the pressures of impactful exploitation or uncertain and surprising disturbances (Muradian, 2001). Failing ecosystem services then impose growing and compounding compulsory costs on human societies and economies, illustrated by the unfolding impacts of climate change. Further stresses eventually cause natural capital to fail, and its path-dependent complex, self-organizing systems may not recover for many human generations.

1.2. Fabricated private capital production

The bell shaped curve in Figure 1 tracks the value of private, fabricated production of marketable goods and services over time and is similar to a related curve proposed by Matutinovic et al. (2016). It begins at zero, at the start of economic development, and rises at first convexly with increasing marginal returns as more and better technology is employed up to the point of diminishing returns (PDR). Private production then grows concavely with diminishing marginal returns until it peaks at the point of maximum possible production (MPP), given a set of available technologies and the associated externality impacts that negatively affect real economic growth. As still more private capital is deployed, the curve declines concavely as the compounding costs of lost ecosystem services increasingly offset and overwhelm gains in private production from private capital (Daly and Farley, 2011, p. 20).

This curve's tragic shape is fundamentally essential to ecological economics. It assumes that economic development is optimized, without making mistakes, all the way across Figure 1 according to established growth theory. The best proportions of capital, labor and resource employment are correctly discovered and adjusted to overcome or prevent recessions or depressions (Solow, 1956). The reversal of growth in Figure 1 is instead due to factors beyond firms' direct control that mainstream development theory discounts, ignores or forgets. These are externality costs that firms spread elsewhere in space and time which rapidly grow due to compounding natural capital failures until they circle back en masse as compulsory and crushing private costs (Hardin, 1968; Diamond, 2004). Conventional economists do not readily contemplate this potential novel and disastrous outcome because they are dominantly disciplined only by past experience and data rather than the complex sciences of environmental dynamics and evolutionary emergence (Hodgson, 1997). What has not been recently observed and understood is presumed to be so improbable as to be outside warranted science.

1.3. Private capital maintenance

The upward sloping curve in Figure 1 tracks the costs to all private parties of maintaining all manner of fabricated capital, or anthropogenic assets, that they own. It begins at zero when there is no private capital to maintain. It rises slowly at first as there is little and mostly new technological capital, but then rises convexly with increasing steepness as there is ever more older and obsolete capital to be maintained or replaced.

1.4. The 'natural' trajectory of economic development

In a maximally free and 'natural' economy deployment of private capital stops at Point A in Figure 1. This is where the marginal value of added aggregate private production equals its coincident marginal private costs. Further net employment of capital will not be profitable. This is not an ideal, stable, equilibrium 'settlement point' from comparative statics theory in economics. There is no production of ecosystem services at Point A because natural capital systems have failed and consequently the private economy is already in freefall, likely with social instability and strife (Beck, 1999). This is the doomsday outcome that motivates ecological economics. It necessitates a different economic 'settlement point' further to the left in Figure 1, where production of commercial goods is not rapidly declining, natural capital systems have not failed, and those systems remain resilient to sustain human life and an economy.

1.5. Radically grounded value theory

The MMERV asserts that the values on the left and right axes in Figure 1 are commensurate and both can be measured in a monetary metric off the left axis. Both axes measure an absolute amount of production on a ratio scale grounded at a real zero value at the bottom of Figure 1. The full height of both production curves are matched at their maximum potentials to give both forms of capital equal value standing. This equating of commercial and ecological potentials is necessary to keep natural capital assets within sustainably functional bounds (Perrings, 1991). Commercial goods and services are presumed equally essential to human needs and social survival as ecosystem services. This method of commensurate valuation is deeply radical to conventional economics, which typically only admits valuations measured by comparative marginal changes along abstracted, self-referential interval scales, i.e. market prices (Gramm, 1988; Fourcade, 2011). The MMERV instead employs real values measured on normatively meaningful ratio scales to account for the wealth associated with ecosystem services, as opposed to ungrounded marginal prices on interval scales (Pearce and Hamilton, 1996).

2. Investments in Natural Capital

The objective of ecological macroeconomics is to prevent the 'natural' settlement point of economic behavior from reaching Point A in Figure 1. It might instead remain closer to the point of maximum potential production (MPP) where private productivity is not yet declining in ways attributable to natural capital degradation and natural capital productivity has not failed and might remain resilient.

This is achieved by investments in natural capital maintenance depicted in Figure 2. The added cost of such investments moves the total maintenance cost curve up, as shown by the arrows pointing up and to the left. This effects a new 'settlement point' of A' at a higher level of long-term private production. These investments also lift the natural capital productivity curve up, as shown by the arrows pointing up and to the right, so that natural capital productivity is no longer below its tipping point into failure. The private capital productivity curve has fallen, as shown by the downward pointing arrows, due to the reallocation of resources from private capital production to that of needed ecosystem services. Figure 2 also shows gains and losses in these over logical time to Point A', as well as associated changes in short-term new private wealth creation.

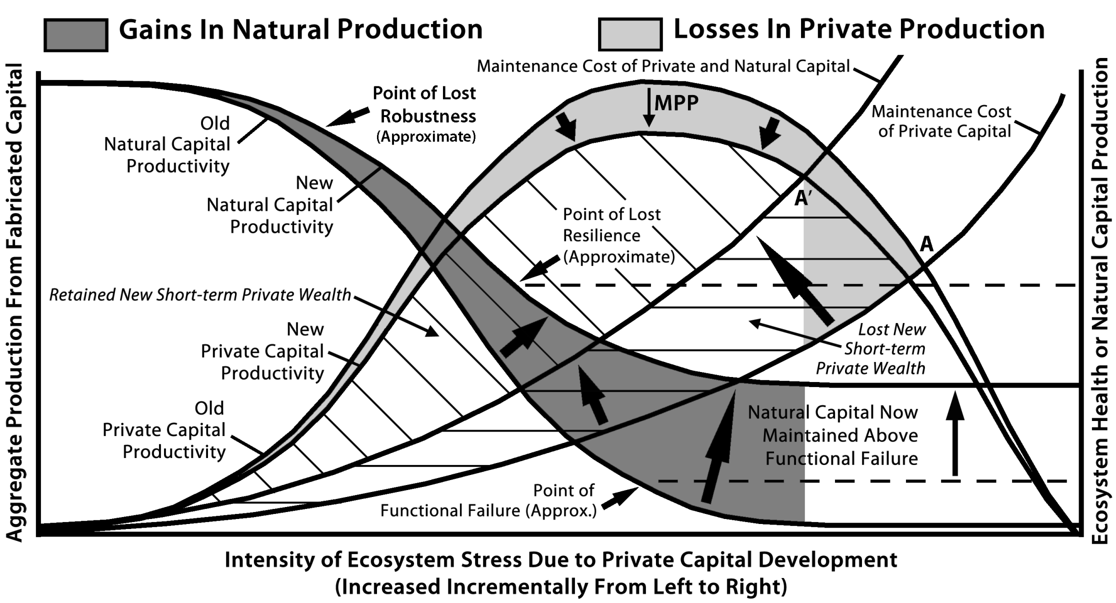

Figure 2. Wealth effects and production gains and losses along logical time in the basic MMERV.

The reformed macroeconomic behavior 'settling' at Point A' in Figure 2 is still suboptimal. It is difficult to redraw that graph to depict a better result in ways consistent with reasonable interactions of the component curves, i.e. lost natural capital resilience must be associated with declining private productivity in logical time, albeit not perfectly in real time. Point A' is suboptimal because long-term private production is not maximized near Point MPP; and the natural capital health curve is too low there. It is below the tipping point of lost resilience and not sustainable over the long term. The following sections explore solutions to these deficiencies.

3. The Sustained Yield Solution?

3.1 Old theory and the essentials of a solution

Conventional environmental macroeconomics and policy often advocates an alternative optimal 'settlement point' in economic development, at Point MPP in Figure 1. Declining ecological stability and resilience, and declining ecosystem services, can contribute to diminishing positive returns to private capital up to that point; but further losses in natural capital productivity should be prevented if they are expected to eventually effect a decline in private production. This is the doctrine of "sustained yield" from natural resources, often applied to limit fish catches or timber harvests at their rates of natural regeneration (Brown, et al., 1987). This theory of sustainable development (Goodland, 1995) is described in Figure 3, except now with a revised horizontal axis whereby the intensity of ecosystem exploitation somehow 'stops' at a value of '60' at the maximum sustainable production of private services along an arbitrarily enumerated scale there.

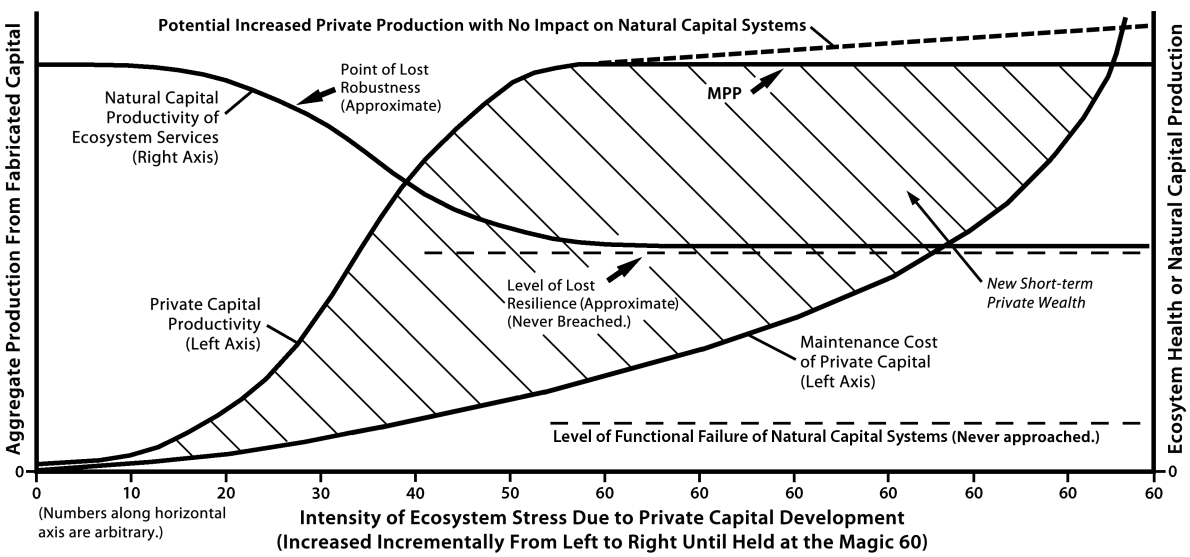

Figure 3. A macroeconomic trajectory describing the sustained yield theory of economic development.

The idealistic conventional sustained yield theory depicted in Figure 3 entails freezing private capital deployment using prevailing available technology that determines its maximum productivity at Point MPP. New 'green' technologies that increase private production without imposing any additional stresses on natural systems may be invented (Jänicke, 2012) represented by the dashed curve on top of Figure 3. With or without this additional 'green' growth, Figure 3 does suggest an objective for sustainable development graphical theory: to have steady or growing private production while maintaining a resilient level of natural capital production.

3.2. Fallacies of sustained yield theory

The flaws in this sustained yield theory relate to its facile comparative statics solution where 'time conveniently stops' whence at graphical optimum, but mainly to several unsupportable assumptions.

One flaw involves how the natural productivity curve must be drawn very high at this 'stopping point' in Figure 3 to make sustained yield theory viable, as opposed to how it is more realistically drawn in Figure 1. This artificially high natural productivity curve assumes that damages to natural capital incurred up to maximized private production will not produce future irreversible losses in the fundamental productivity of natural capital (Cleveland, 2003) so as not to compromise nature's permanent resilient functioning (Figure 3). For example, converting a forest to a regularly harvested monoculture of a commercially optimal tree type is assumed to be as resilient as a more diverse forest resembling a native forest.

This belief in magically beneficent nature in all modified or exploited forms is more a matter of economic or cultural faith than empirical fact. Damages to self-organizing, complex-adaptive, natural capital systems are path-dependent and self compounding so the 'train wreck' to their lost resilience and ultimate failure may be well under way before maximum potential private production is reached (Perrings et al., 1995). This is why the natural capital productivity curve declines much faster in Figure 1 than in Figure 3. Private production may actually begin declining -- due to failing and unstable ecosystem service flows -- when it is too late to reverse the damages at acceptable costs even if it is technically possible (Barbier, 2011).

Another related flaw in sustained yield development theory is its assumption that the predominant or only measure needed to sustain natural systems' resilience is to stop their rate of exploitation at some carrying capacity (the magic value of 60 in Figure 3). At such a sustained yield point, there are assumed to be no substantial, non-commercial private investments, or commercial opportunity costs, required to keep natural systems in resilient functioning. The simple prescription of limiting harvests (i.e. of fish or timber) assumes that ecosystems will forever remain robust or adequately resilient to reliably regenerate these harvested ecosystem services. Unexpected disturbances, uncontrollable events, and cumulative impacts from other indirectly related commercial activities will inevitably compromise ecosystems maintained on the edge of exploitive collapse (Biggs et al., 2009). Additional direct interventions in ecological rehabilitation will therefore also be needed and these investments and their private costs are not included in Figure 3.

The sustained yield growth theory specified in Figure 3 assumes that natural capital productivity does not decline very much in the run-up to maximized private production. People will somehow be guided to carefully choose ecologically gentle forms of private capital and deploy them at a careful rate that prevents permanent damage to the resilience of natural capital systems; whereas history shows that economic competition almost always compels people and newly developing economies to do otherwise (Stern, et al, 1996).

The trajectory in Figure 3 also assumes that natural capital productivity will indefinitely remain stable at a low but resilient carrying capacity while maximum private production is indefinitely sustained. But persistent high levels of private wealth-maximizing exploitive stress on any complex adaptive system, whether natural, cultural, political or economic will likely inevitably compromise its resilience, particularly with inevitable, uncertain and outside disturbances (Holling, 2001).

Once the carrying capacity of natural capital is reached in Figure 3 sustained yield theory assumes that everyone will somehow agree upon and successfully enforce "mutual coercion, mutually agreed upon" (Hardin, 1968) to prevent deployment of more or new private capital that damages natural systems past their aggregate tipping point of lost resilience. This is a highly problematic assumption (Ostrum et al., 2002). People must accept that no more private capital production is to be gained above its 'fixed' maximum at Point MPP in Figure 3. The inexorable arrow of time, constant change, enterprising human nature, and inevitable new problems that must be solved all defy social acceptance of a stable economic equipoise. All the requisite complex self-organizing social and economic processes driven by problem solving, ambition, innovation, competition, the need to create surplus wealth to pay for these adaptive activities and more are assumed away.

3.3. Compulsory tragedy?

The obvious must be noted. Figure 3 incorporates the naïveté of sustained yield's behavioral assumptions. It wills away the arrow of time and mathematical logic of the tragedy of the commons. Increased deployment of impactful private capital produces short-term gains concentrated toward consumers and private capital owners via commercial markets and purchasing-power incomes. Natural capital costs are spread into the future and thinly onto many people and these only indirectly and eventually impact private wealth. Fixing the level of private capital at Point MPP not only attempts to stop time; it denies people's compulsion to deploy more impactful private capital beyond natural systems' carrying capacity in search of new wealth. New technologies will be invented, and these likely may not be benign to the bearing capacity of natural capital like those that produce the dashed growth curve at the top of Figure 3.

Figure 4 describes a trajectory consistent with this compulsion. It would apply if new technologies offer a higher MPP' but also break down the resilience of natural capital. Deployment of such new private capital will be hard to resist because additional short-term new wealth creation exceeds long-term lost new wealth, as indicated in Figure 4. The 'settlement point' for the macroeconomic behavior in Figure 4 is now Point X, but the applicable natural capital productivity curve is now the one at the bottom of Figure 4 so this economy will crash like that in Figure 1.

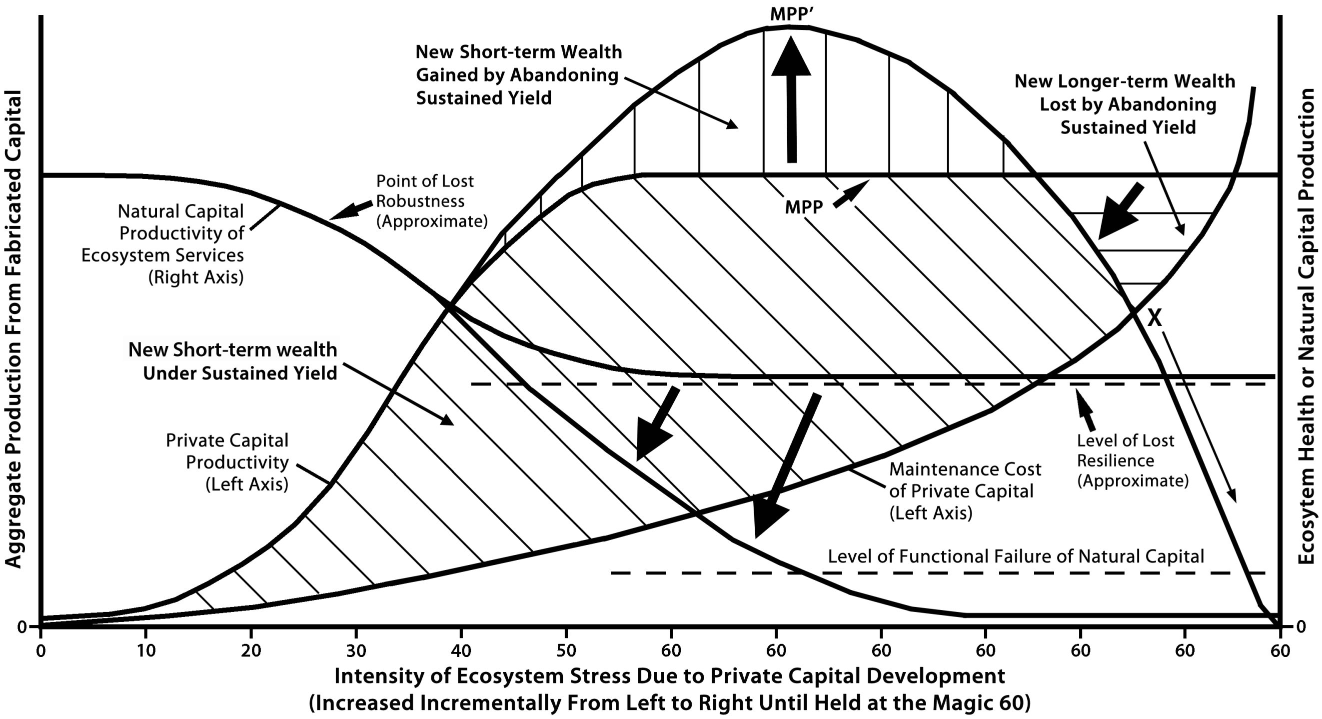

Figure 4. A trajectory describing abandonment of sustained yield.

4. Green Private Capital Contributions

The 'natural' doomsday economic theory in Figure 1, and the inadequacies of the theoretical solutions in Figures 2-4, suggest that more 'unnatural' economic behaviors are needed. These can be new investments in alternative private capital that is less damaging to natural capital, in addition to the sunk private costs in maintaining natural capital shown in Figure 2. Such 'green' fabricated capital would produce the same or more private goods and services at much lower costs to natural capital systems. These additional investments are shown in Figure 5. The overall cost curve has risen again compared to Figure 2, moving the 'settlement point' from the previous A' to A". Costs now include added private research and development costs of green technology, short-term opportunity costs of forgoing the deployment of conventional 'brown' technology, and government or other subsidies needed to compensate private capital owners for these short-term losses to produce long-term public benefits.

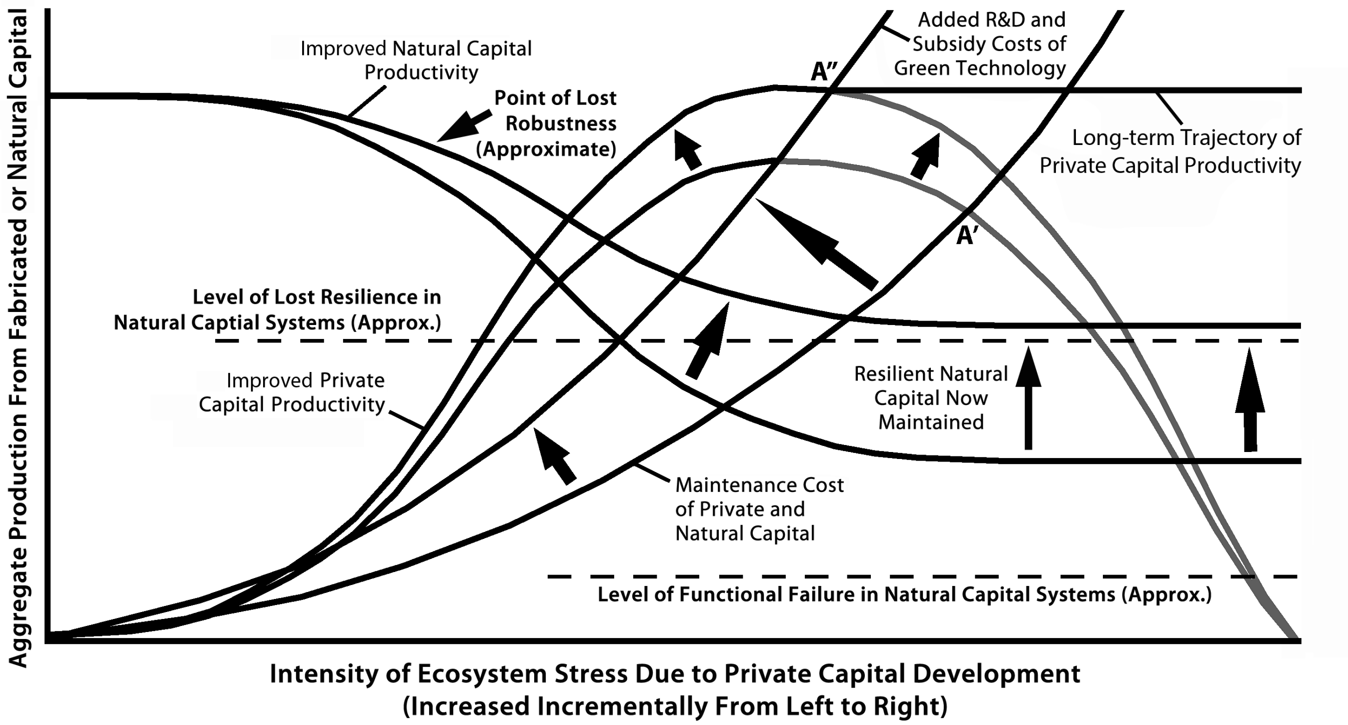

Figure 5. A trajectory adding investments in green technology to those in natural capital maintenance.

The private capital productivity curve in Figure 5 has risen to make up for some or all private capital losses found in Figure 2. This is because green technology enables restored production of private services as a replacement for the brown technology that had to be forgone in moving from Point A to A′ in Figure 2. The natural capital productivity curve in Figure 5 has optimistically risen above the tipping-point level of lost natural capital resilience; assuming that green technology might substantially reduce the stress on natural capital systems with each step of capital application to the right across Figure 5. This theoretical economy, now at Point A″, has reached the target for sustainability set out in Section 3.1 and Figure 3, but potentially without the artificial, onerous and unpopular command-and-control sustained yield measures to freeze stresses on natural capital. Figure 5 describes a sustainable economy that may not crash. But it artificially ‘sits’ at the Point A″ ‘settlement point’ that cannot be frozen in equipoise forever, an issue that will be explored in Sections 6 and 7.

4.1. Gains and losses from green private capital

Figure 6 is the same as Figure 5, but with five areas of total short-term value gains and losses mapped as a consequence of investments in green private capital from Point A′ to Point A″. Gains in natural capital productivity are substantial. Gains and losses in private capital productivity over logical time roughly offset each other. Gains in private production occur with lost new wealth creation, with the gains going to firms that successfully invest in green technology and ‘own’ the rise in the private capital productivity curve up to Point A″. Other firms would be ‘weeded out’. While new private wealth creation is about the same in Figure 6 at Point A″ as in Figure 2 at Point A′, both these are still substantially less than such gains in the unsustainable economy in Figure 1 at Point A.

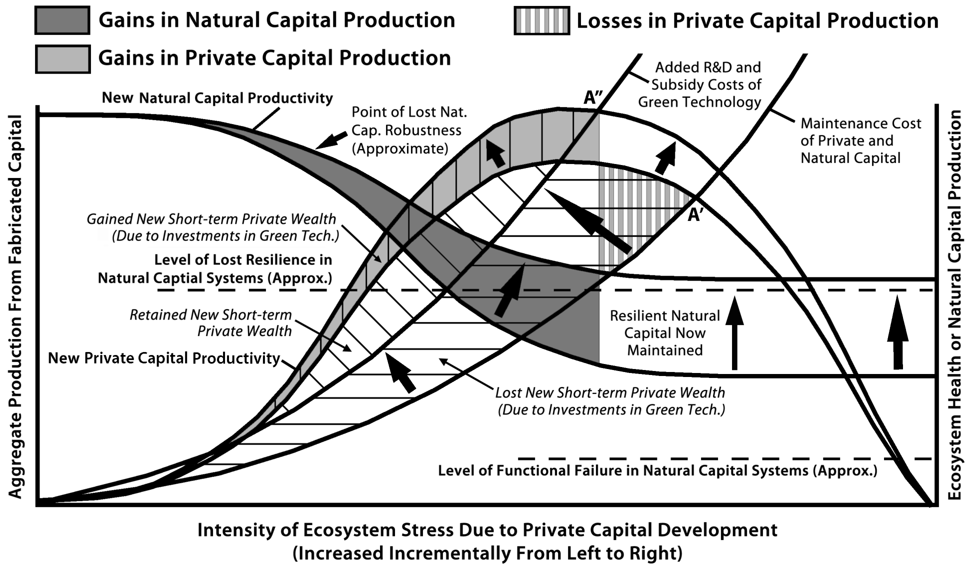

Figure 6. Wealth effects and production gains and losses along logical time with added investments in green technology.

5. Whither Robust Ecosystems?

The same macroeconomic behavior in Figures 5 and 6 ‘settles’ at a much more sustainable ‘optimum’ at point A”, but natural capital health has only maintained resilience and not robustness. The MMERV posits that investments in both natural capital and green technology will be insufficient to allow natural systems to regain historically high biodiversity and self-organized complexity to be maximally adaptive to inevitable major disturbances or unexpected stresses. Natural capital will remain too stressed and subject to irreversible damages. These impacts are associated with the diminishing, but still positive, returns to private capital as the economy approaches point A” (from the left) in Figure 5.

The theoretical solution to these deficits in maximum sustainability would be the macroeconomic behavior in Figure 7. Additional investments in natural capital have raised the natural capital health curve up to a robust level. As drawn, there is about as much gain in the productivity of natural capital as losses to private production.

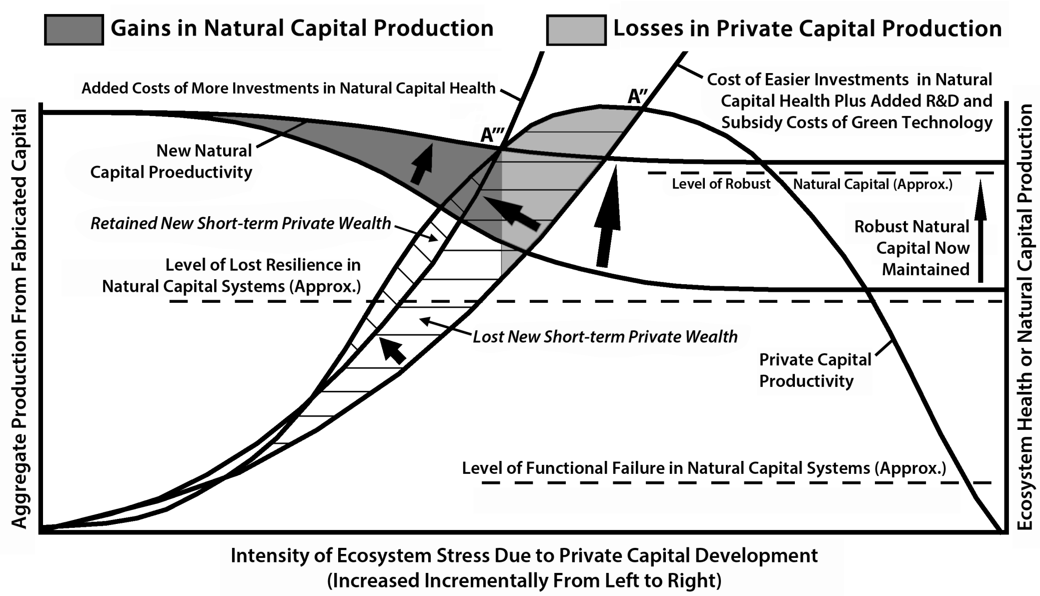

Figure 7. A trajectory attempting to restore ecosystems’ robustness.

The further investments in natural capital in Figure 7 represent more diversion of resources from private capital development to natural capital maintenance, which has raised the cost curve more than in Figure 6. The corresponding drop in the private capital productivity curve is not drawn in Figure 7 for graphical simplicity but could be appreciable. This behavior leads to a new 'settlement point' at A''', back and down the private capital productivity curve. This has eliminated some of the natural capital damage that would otherwise have effected some diminishing positive returns to private capital had the settlement point A" instead been achieved. This move downward in private productivity from Point A" to A'" effects a double private cost not found in previous graphs. Forgone returns to private capital, by not getting up to Point A", are now added to the natural capital investment costs entailed by moving from Point A" to A'". These comprise the high cost of maintaining insurance against long-term economic instability that ecological robustness provides.

Of more immediate consequence is the 'profit squeeze' in Figure 7. Most short-term gains in new wealth creation are eliminated. New wealth is needed as an economic surplus for problem solving and making creatively adaptive investments in private, natural and public capital. Wealth creation that is retained in Figure 7 is, by inspection, very probably insufficient for these purposes, likely rendering this economic behavior favoring robust ecosystems unsustainable. The MMERV suggests that massive investments in natural capital systems to maintain robustly diverse ecosystems are not a viable option.

6. Trajectories of Long-term Ecological Economic Evolution

Point A" in Figures 5 and 6 represents a peak 'settlement' condition of sustainable development in logical, not real, time. It is where the MMERV indicates the prosperous deployment of private capital will stop due to necessary and substantial investments in natural capital maintenance and green technology. More private capital deployment instead of these investments would be unprofitable, in the short-term welfare economic sense, only if the value of natural capital is accounted for using the value theory of the MMERV. This is required to produce sustainable development.

The macroeconomic behavior described by Figures 5 and 6 is likely impossible. It 'settles' at a kind of steady state or equipoise of private capital constrained by the needs of natural capital systems. Time does not stop and the world never settles down into stability. The very process of economic growth up to Point A" causes scaling effects on all social and ecological systems that require never-ending adaptive evolution (West, 2017). Populations grow. New problems arise. People are enterprising. Ecosystems change. Innovations happen. New economic surpluses are needed to support these creative and adaptive processes.

The arrows in Figure 8 depict postulated ways that a sustainable economy can evolve and grow. They denote evolutionary changes that can allow the sustainable 'settlement point' at A" to move up and to the right. Green technological innovations can increase production of private goods while incurring little damage to natural systems, or may incur damages that are much less costly to prevent or reverse than the coincident private value created. This would correspond to the whole private capital productivity curve moving up, indicated by the 'A' arrows in Figure 8. Development of more efficient or effective green technology or natural capital maintenance techniques can improve the resilience of natural capital systems at the same or less cost. This would correspond to a rise in the natural capital productivity curve, indicated by the 'B' arrows. Less costly or more cost-effective techniques for ecological restoration and maintenance might be invented, or the same might also be achieved for private capital maintenance costs. Either or both would correspond to the total all-capital maintenance curve moving down, indicated by the 'C' arrows.

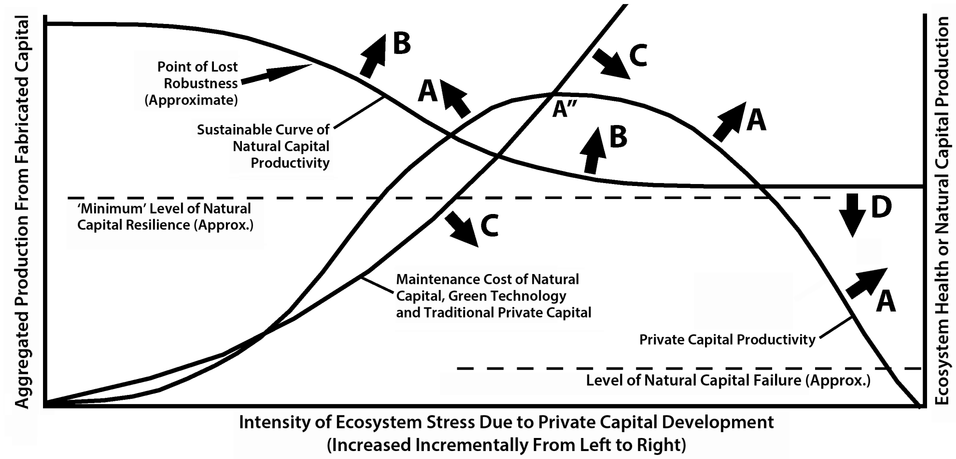

Figure 8. Ways that economies might evolve toward sustainability.

The two arrows next to the 'D' in Figure 8 denote a more radical theoretical possibility in producing sustainable economic growth. This would involve the obsolescence of natural capital systems. New forms of private capital might replace natural capital in providing the same or substitute services that natural capital systems previously provided. This replacement could 'harmlessly' allow a drop in the natural capital productivity curve, indicated by the arrow above the 'D' in Figure 8. This drop in ecosystems' health might not have its previous indirect and adverse consequences on private capital productivity, so the downward-sloping tail of the private capital productivity curve would rise, indicated by the arrow below the 'D' in Figure 8. Investments in natural capital would also be less necessary, so total all-capital maintenance costs would lessen, corresponding to another cause of the 'C' arrows in Figure 8.

6.1. Sustainable growth over time?

If an economy were to achieve the sustainable development settlement point A" in Figures 5 and 6, could it grow sustainably from there and produce new private wealth? Figure 9 describes the theoretical solution entailing persistent green innovation (Solow, 1974; Clark and Juma, 2013; Gowdy, 1994). It describes a theory similar to a mathematical one developed for energy and climate change by Ayres (1987). The letters represent a successive flow of comparative static 'settlement points' along a gradually growing trajectory of private production. Private capital productivity would have to keep improving in ways that harmonize with long-term natural capital resilience (Ekins, 1999), marked by the lower time-step arrows pushing the private capital curve up in Figure 9. Less costly maintenance of natural capital would have to be simultaneously and continuously deployed, indicated by the upper arrows pushing the all-capital maintenance cost curve down. Those aggregate costs would have to be reliably less than the total receipts from private capital to maintain a normal profit margin, shown by the difference between the long-term trajectory curves at the top of Figure 9.

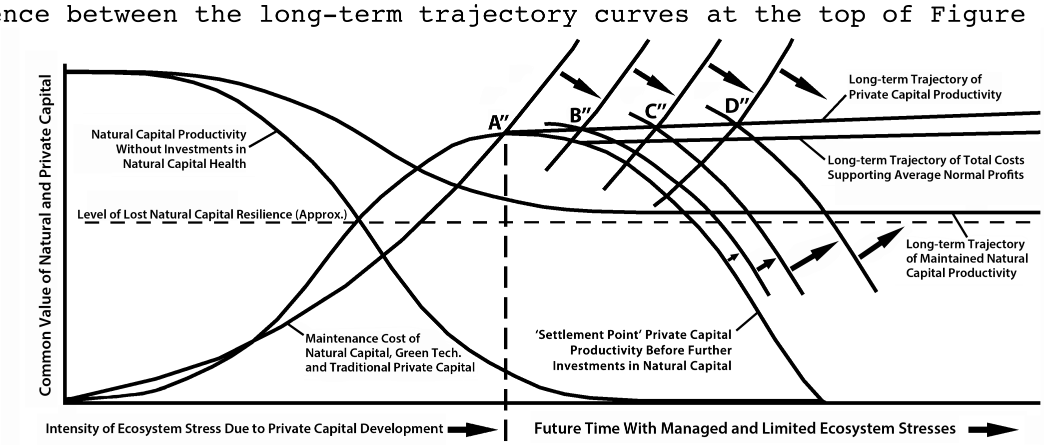

Figure 9. Long-term evolution of the solution in Figure 5.

6.2. Muddling down softly

If the sustainable macroeconomic behaviors posited in Figures 5 and then 9 fail to occur, some technically and politically feasible investments in natural capital restoration and maintenance may still occur. This could achieve a halfway sustainable condition like that in Figure 2, which might produce a future trajectory like that in Figure 10. From the settlement point in Figure 2, viable further investments in natural capital would be made, but these would not be enough to achieve long-term natural capital resilience. The consequent attenuated losses in natural capital health would more gradually impose costs upon private capital productivity, probably with shortening temporal lags over time. Losses in ecosystem health could be more gradual, forestalling inevitable collapse perhaps for generations. In more developed economies where this scenario may more likely prevail, gradual aggregate losses in genuine private wealth derived from natural capital failures may be 'papered-over' by fiscal accounting gymnastics and monetary engineering to maintain vital nominal positive returns on private capital (Seeley, 2017).

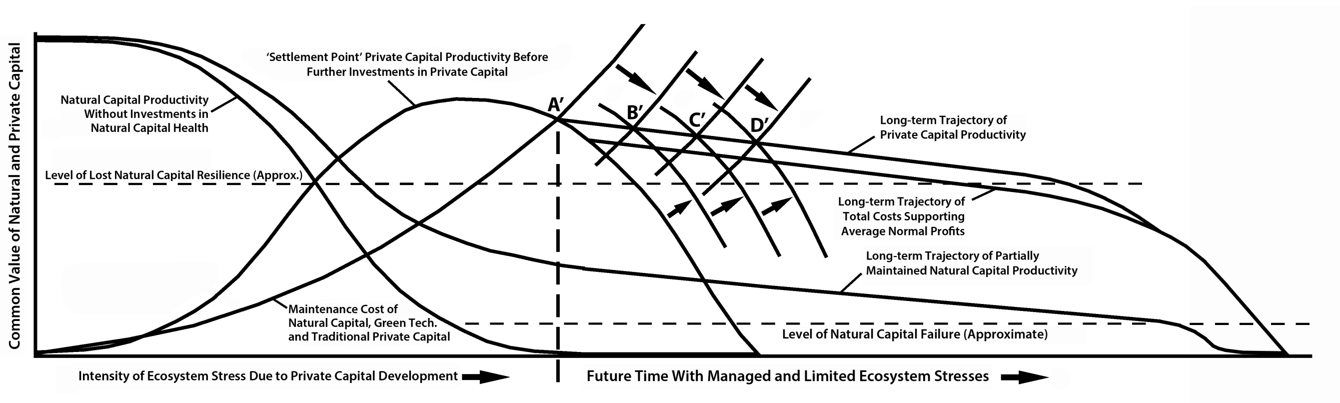

Figure 10. Trajectory of muddling down softly to delayed collapse.

6.3 Replacing natural capital with fabricated capital

Growing losses in essential ecosystem services, due to the deficit in natural capital investment tracked in Figure 10, might be made up for by the 'artificial' production or co-production of ecosystem services by fabricated capital. This highly speculative scenario would require massive and timely invention and deployment of innovations to compensate for declining health of increasingly unstable natural capital. These would have to produce stable supplies of nutritious food, safe air, clean water, climate stability, landscapes that support psychological health, etc. in ways that nurture civil peace without repression, stable cooperative cultures, sound child development, etc. If actually possible, such production would require institutional economic structures to incentivize and reward large-scale efficient production of artificial ecosystem-service-producing capital. This will require innovative ownership or financing of such capital by a diversity of novel private, public and partnership entities (Merk et al., 2012).

A macroeconomic scenario dependent on successful artificial nature is illustrated in Figure 11. Some time after reaching the unsustainable A' settlement point, marked declines in private capital productivity initiate crises in social stability and human health as social, microeconomic or technical forces compel inadequate maintenance of natural capital systems to failure. These disturbances may instigate investments in artificial ecosystem-service-producing capital, drawn as the rising curve with arrows pointing up and to the left in the lower right of Figure 11. These might replace ecosystem services from irreversibly damaged natural systems. As shown in Figure 11, such new capital's effective production of ecosystem services may grow over time to gradually substitute for or replace declining services from natural capital systems. This might allow for stable, modest aggregate economic growth if a society can navigate the transition technologically, politically and institutionally.

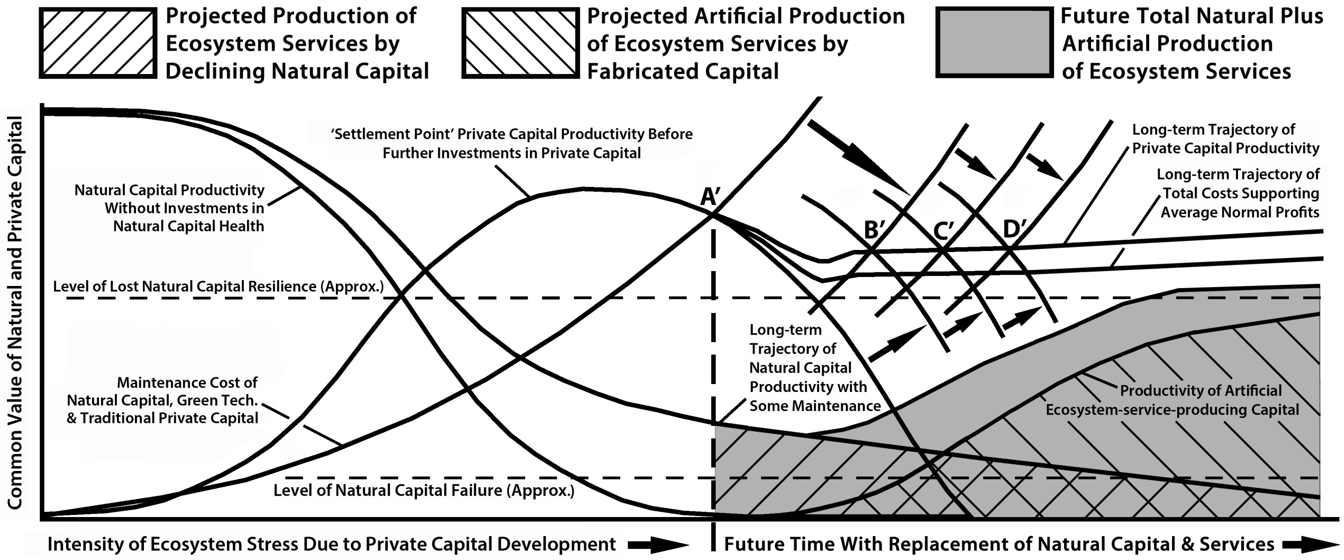

Figure 11. Replacing ecosystem services from natural capital with those from fabricated capital.

Figure 11 describes the necessary conditions for economic development with artificial nature. Growth in private productivity supported by artificial ecosystem services is described by the arrows pointing up and to the right at each time step. Reductions in private and natural capital maintenance costs supported by artificial ecosystem services are described by the arrows pointing down and to the right at each time step. In this idealized and highly speculative scenario, a long term trajectory of very gradually growing private capital productivity might occur as represented by the top curve at the right end of the graph.

One problematic aspect of this Figure 11 scenario is the required long-term stability in the cost of artificial ecosystem-service-producing capital. At each time step, the capital maintenance cost curve must keep falling (the downward pointing arrows) so that they cross the capital productivity curves at the settlement points (B′, C′, D′…) at non-declining levels. Initially this might be plausible because creating some artificial natural capital might have a lower marginal cost than trying to repair particular hopelessly destroyed natural capital systems. An example would be constructed wetlands, rain gardens and bio-swales in cities where natural hydrologic water-cleansing and flood-elimination systems are gone. But the marginal cost of other required artificial nature technologies might prove prohibitive, as more and bigger natural systems fail more. An example might be attempts to 'sweep' carbon out of the atmosphere to restore a stable and habitable climate.

6.4 Debt financed natural capital investments

Figure 12 describes a simplified, pure-case trajectory for developed economies that are committed to sustaining the resilience of natural capital systems but largely unwilling to privately finance the required investments. This highly speculative scenario assumes that all necessary investments will be made to sustain natural capital systems' resilience but also that short-term private capital productivity and profitability will be held harmless. Virtually all the costs of these necessary and not discretionary investments will be financed by debt against future generations. These leveraged investments will include the costs of ecosystem restoration, green capital and artificial production of ecosystem services that are not privately profitable.

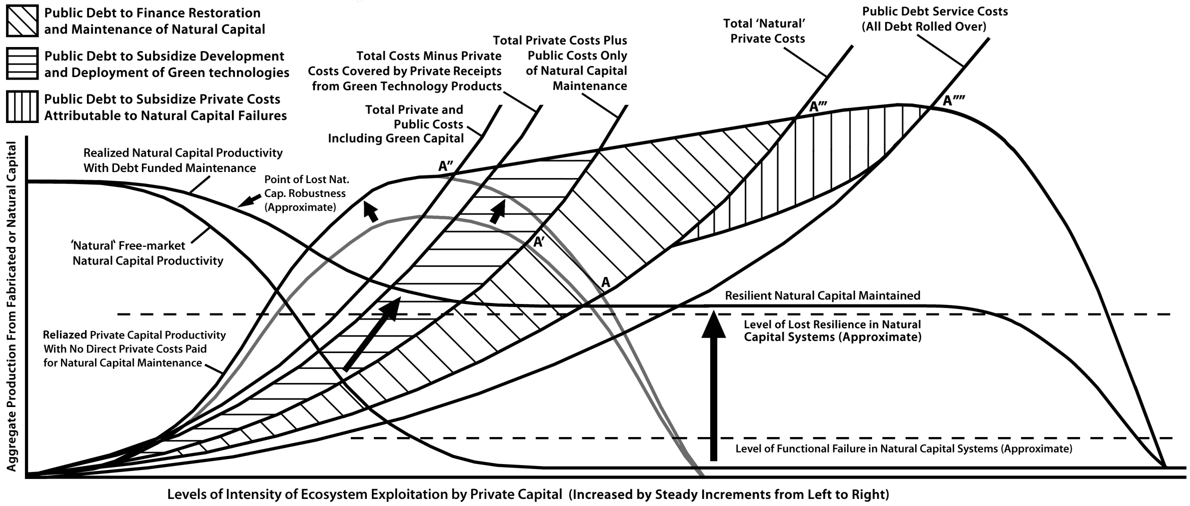

Figure 12. Trajectory with investments in natural capital and green technology financed mainly by public debt.

The resulting macroeconomic behavior described by Figure 12 shows that the maximization of commercial services by private capital is no longer limited by the need to pay for the costs of natural capital resilience nor by the need to bear the involuntary burden of costs imposed upon private production by the consequences of natural capital failures. Both of these are covered by public debt. This pays for moving the economy from Point A to A′ to A″ as described previously. Without the burden of these costs, private capital can now grow to its new 'settlement point' at A′″ where private receipts equal private costs and further growth would be unprofitable. At this Point A′″, owners of private capital might succeed in unloading some of their private costs onto the public debt by using the argument that some of those costs are caused by natural capital failures which is the public sector's fault and proper liability. This additional public financing of private debt is the vertical cross hatched area near the top right in Figure 12. It could allow private capital to grow up to the new 'settlement point' at A″″.

The limiting factor of private capital productivity is now the broadly shared service costs on the compounding debt attributable to compounding stresses on natural capital with attendant compounding costs for its maintenance, repair and artificial replacement. These mounting debt service costs will likely inevitably and tragically force a decline and then crash in private capital productivity, much like that forecast by the basic MMERV in Figure 1, and shown in grey in Figure 12. This decline will now happen later on than if the debt-financed investments in sustaining natural capital resilience had not been made. At Point A″″, when income from commercial services is entirely consumed by debt payments, the private capital economy declines precipitously. There is then no means to finance natural capital investments so those systems also decline to failure. These costs then compound the failure of private capital in a death spiral.

6.5 A more probable scenario

Figure 13 depicts an over-simplified macroeconomic trajectory that may be occurring in some countries and perhaps for the whole earth. The curves labeled as "initial" in Figure 13 correspond to the 'natural' economic trajectory of the basic MMERV in Figure 1 that assumes a given state of technologies. Rapid technological change is driving down private capital production costs moving that curve down to its lower track in Figure 13, as shown by the big solid black arrow. At the same time, new private capital technologies increase productivity to raise that curve, as shown by the small arrows. Together over time these provide an opportunity to produce the additional new wealth shaded in Figure 13, particularly for enterprises enjoying these factors. This drives macroeconomic behavior to 'settle' at Point B. This change in 'natural' economic behavior, by itself, will intensify stresses on ecosystems simply by accelerating deployment of private capital and pushing it, and its associated stresses, further to the right.

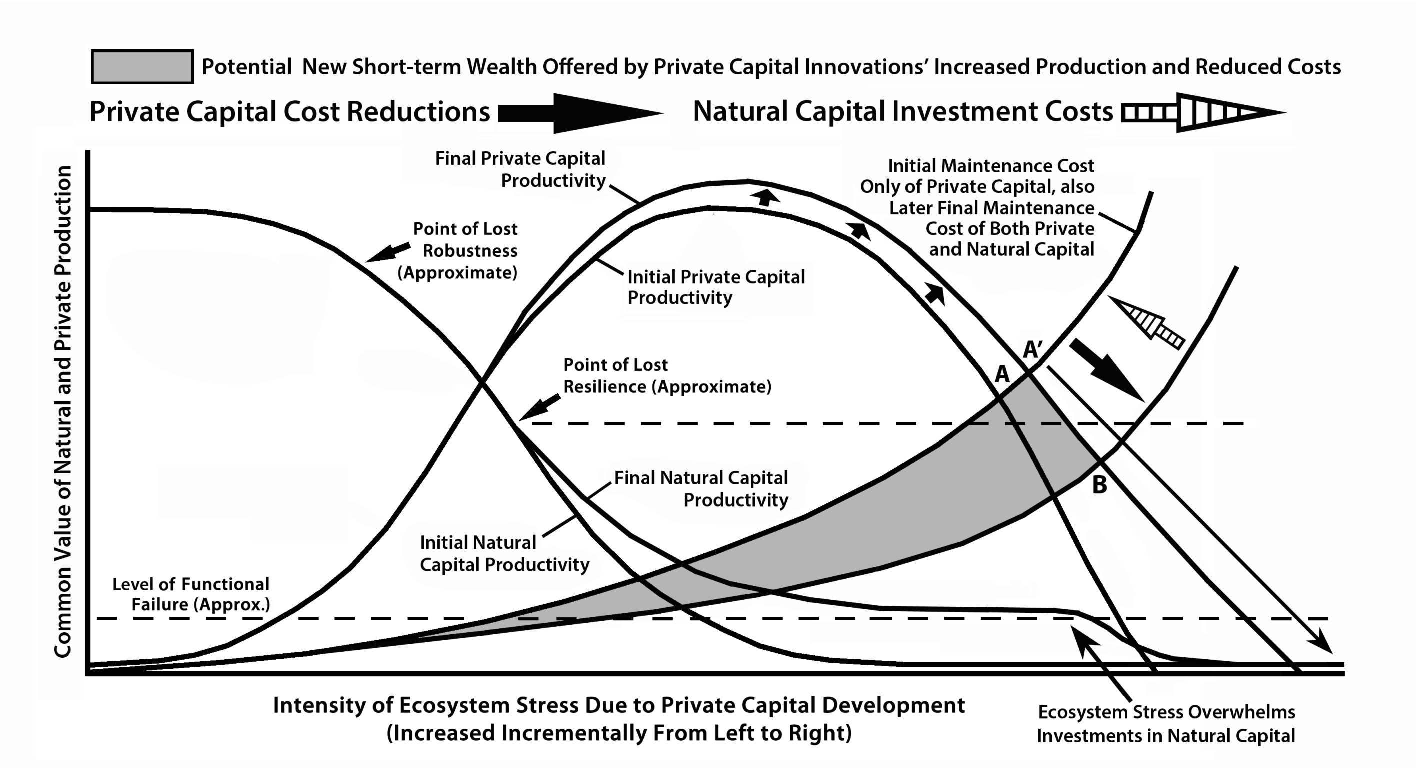

Figure 13. Trajectory where natural capital investments only offset increased ecosystem stresses enabled by private technological innovation.

As with the basic MMERV in Figure 1, aggregate marginal private production declines in Figure 13 on the way toward Point B, due to the compounding pernicious effects of declines in natural capital health with overall loss of resilient functioning. This will elicit a response, which are investments in natural capital maintenance and restoration in the scenario depicted in Figure 13. These investments are assumed to be limited to those that are politically, socially and fiscally possible. As drawn, they are only just enough to cancel the aggregate cost savings from technological innovation and return the total cost curve back up to where it started, as shown by the big striped arrow. This drives the 'final' settlement point to A' in Figure 13.

This new 'settlement point' at A' is not much different than that before technological innovations at Point A, as measured along the ecosystem stress gradient across the bottom of the graph. The problem of sustainable development is not solved because Point A' is as likely to produce ecosystems' failure as Point A. The investments in natural capital are seeking to counteract the very high ecosystem stress associated with Point B, that private capital is pushing toward. These investments may succeed in raising the 'final' curve tracking ecosystem health above failure for some time, as shown in Figure 13. But, the persistent growth of ecosystem stresses toward Point B will overwhelm the limited natural capital investments to finally tip ecosystems into functional failure. This will drive the economy from Point A' into collapse, as shown by the long arrow at the bottom right of Figure 13.

Figure 14 shows how this macroeconomic trajectory is a bit better than the 'natural' trajectory in Figure 1. Although both trajectories end in economic collapse, the new Figure 14 trajectory produces unsustainable gains in both private and natural capital production and a forestalled collapse. The owners and beneficiaries of private capital innovation enjoy the gains denoted by the grid-shaded area while the economy still lives. But, in the end, the same value of these gains is lost across the larger economy as wasted general public expenditures.

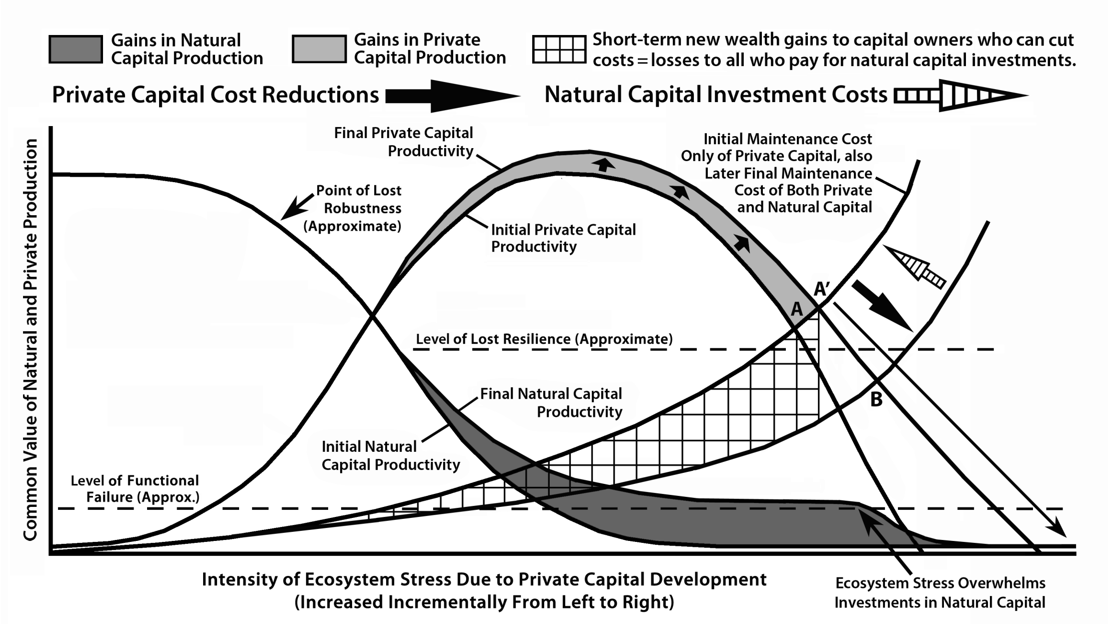

Figure 14. Wealth effects and production gains and losses along logical time for the trajectory in Figure 13.

If the growth in private productivity attributable to technical innovations were much greater than drawn in Figures 13 and 14, that would raise that curve higher up the graph, further in the direction of the small arrows. This would drive the new settlement point (A′) along the cost curve up and to the right. Ecosystem stress would therefore be even higher than at Point A′ in Figures 13 and 14, and the same unsustainable scenario would still apply.

7. Discussion

The handful of projected macroeconomic scenarios graphed and introduced above are only a few selected relatively pure-case examples. Future economic evolution, and further theoretical proposals, may combine elements from all or some, and others not developed here, in complex ways. All these will grapple with the emerging vexing and intractable conflict between powerful private capital and wealth versus public capital and health derived from self-organizing environmental, cultural and institutional complex systems that are declining in power and viability.

7.1 The biggest core problem

The least developed aspect of the MMERV, and the most likely grounds for its rejection, is an inadequate understanding of the economic processes of catastrophic social collapse. This strong possibility is a distinctly fundamental tenant of the MMERV, but is largely assumed and not described or modeled in any specific way. Environmental scientists and ecological economists have not adequately hypothesized a ‘snowballing’ of ecosystem failures to explore and develop a theory of future processes of social collapse attributable to climate change with lost ecosystem services (Timmerman, 1981; Davidson, 2010). Just how might natural capital failures gather and compound each other in complex ways to produce a downward positive feedback spiral. There are certainly many vague claims and ideas about this process in the literature, and relevant broadly conceptual (and non-catastrophic) theories of resilience and panarchy (e.g. Holling et al., 2002; Benson, 2014). But these do not describe the economic process of compounding self-organizing system failures in enough theoretical detail to design the efficient and effective investments in natural capital that the MMERV suggests must be implemented (Mennell, 1990). This is the greatest weakness of the MMERV and the usefulness of the analyses presented herein.

7.2 Summary

The MMERV offers a graphical model of aggregate relationships among essential macroeconomic variables to aid clear thinking about alternative pathways of economic behavior. Trade-offs between private and natural capital productivity and attendant gains and costs are formally described showing that financial 'dead weight' investments in natural capital are required along with employment of truly 'green' technologies. Successful maintenance of natural capital health entails lost new private wealth but significant new wealth might be retained if that maintenance proves to be efficient and effective, but not over-reaching (Bretschger and Pattakou, 2018). The private sector must forgo short-term production and new wealth to prevent long-term economic and civil collapse to chaos with massive losses of private wealth and repression of freedoms. Long-term, lesser but sustainable gains in wealth creation can accrue from economic activities investing in both private and natural capital.

This long-term result will entail incessant innovations in both private green capital and natural capital maintenance, and will need to include some wholly artificial production of ecosystem services. It will also entail wealth transfers from traditional owners and workers to many new owners and workers in natural capital maintenance enterprises. Such workers will need to be so employed as private production of marketable goods becomes highly automated.

7.3 Sensitivity issues in modeling and forecasting

All the short- and long-term theoretical scenarios herein are highly sensitive to two types of reality checks. The first is more precision about the shape and interaction of all the curves up to the various 'settlement points' in the MMERV. Researchers need to estimate these using new biometric and econometric methods that couple economic and biological systems and incorporate the direct and indirect impacts of lost ecosystem services on net aggregate private capital productivity. These specifications can enable and profoundly effect estimates of just where different economies and the planetary economy 'sit' along the macroeconomic behavioral paths posited by the MMERV. The interaction of private capital production and natural capital health and productivity described by the MMERV is likely to be generally verified but better understanding of the magnitude of this interaction and how marginal changes in one relate to the other over time might be profoundly informative. Estimates of the shape of the aggregate 'natural' cost curve and its potential shifts in relation to the other curves are critical, difficult to make, and would also be profoundly informative.

The second type of reality check is more difficult to investigate but no less important. Research is needed to estimate the likelihood and 'friction' that different long-term adjustments to the MMERV's curves will encounter, and how these adjustments interact (Figures 9-13). Is it possible to continually reduce the impact of increasingly commercially productive capital on natural capital resilience? Is it possible to continually invest economic resources in maintaining and restoring the resilient productivity of natural capital in increasingly efficient ways in spite of often novel and rapidly evolving stresses from new forms of private capital and ongoing and compounding stresses from legacy insults to natural capital? Can the costs of both the above economic sectors continuously be reduced? Can the introduction of fabricated capital to 'artificially' produce ecosystem services -- instead of from complex, self-organizing systems -- actually aid in the achievement of the goals implied in all the above questions?

7.4. Other challenges

Technical and institutional challenges in maintaining natural capital resilience are daunting and manifest everywhere (Ostrom et al., 2002). The most efficient investments in resilience and green technology -- to produce the trajectory in Figure 5 – may still produce a net very-substantial drop in private capital productivity if the unavoidable trade-offs between private and natural capital productivity are too large to be successfully negotiated. Losses in new private wealth may then be unacceptable to most people in spite of the potential long-term benefits in avoiding social collapse.

The sustainable pathways of macroeconomic evolution suggested by Figures 9-13 are also highly problematic. They require that constantly increasing innovations in natural capital maintenance and replacement obey a kind of Moore's law for the production of ecosystem services. This seems unlikely in this non-information-science realm. Such rapid changes in natural capital systems would certainly not constitute a return to historical forms of robustly stable and self-maintaining ecosystems. The kinds of economic trajectories suggested by Figures 9-11 also require that innovations and problem solving in both private and natural capital productivity be funded by a tenuously maintained modest flow of normal profits. Such available resources, representing a small fraction of total economic production, may prove to be too small and unstable to reliably sustain ecosystem services.

The MMERV graphs offered here pose a question about whether private capital owners and consumers of its products will tolerate net losses in production and profits needed to lift the future health of natural capital from failure to resilience. Will they find diversions of resources to natural capital investments so intolerable and unreasonable as to warrant rebellion? Research should estimate actual short-term profit losses and consequent long-term gains in natural capital health. Studies should investigate voters' and private capital owners' perceptions of such trade-offs, the acceptability of the constraints and common costs they entail, and whether the necessary policies can attain sufficient behavioral compliance to be effective.

7.5. Tendentious economic laws

The form and interpretation of the MMERV will undoubtedly be controversial and subject to contentious critiques and revisions. These will center on two major 'economic laws' implicated by the MMERV: (1) Natural capital resilience cannot be achieved while simultaneously maximizing the creation of short-term commercial production. (2) Catastrophic failure of natural capital systems can and will occur in the foreseeable future with catastrophic consequences upon commerce, freedoms and other vital social systems.

Conventional economists will insist that valid macroeconomic science will always best describe only the left-hand, growing-private-production part of all the graphs offered herein. These claims, based on historically powerful factors, will effectively assert that the frontier easy-growth phase of economic history, with always incidental and essentially insubstantial externality costs, provides the only powerful and enduring description of economic problems. They will assert that catastrophic failure of natural capital systems is either impossible or of little ultimate consequence.

The third major economic law implicated by the MMERV is that very substantial investments in natural capital maintenance and very low impact private technologies are both required to produce sustainable economies. This law is much less controversial until it is understood in the light of the first two laws sketched above.

7.6. Some tendentious assumptions

The MMERV assumes that investments in natural capital health can produce the benefit of restored ecosystems' resilience while effecting only comparatively small declines in private capital production of commercial goods and services. This assumes that the redirection of resources away from private to public capital investments will be efficient in picking only the low-hanging fruit of ecosystem restoration achievements while only sacrificing the least-cost private productivity. It also assumes that such trade-off choices will not unavoidably and fundamentally undermine the future productivity of private capital. The first assumption relies on an expectation that public-interest institutions will be powerful in wise, incorruptible, and fair ways contrary to history and human nature. The second assumption requires that vital natural resources for private capital will always be found and exploited in places and ways that do not destroy the vitality of critical ecosystems, contrary to the likelihood that most all such places have already played out.

The MMERV's greatest essential and durable value lies in bringing natural capital, its products, its reformulated value metric, and its maintenance fully and rigorously into macroeconomic theory and discourse. The MMERV's greatest weaknesses will not likely be within the limited, self-defined scope of macroeconomic theory. These will instead be the theory's failure to incorporate other forms of un-owned social and public capital besides natural capital. Such other productive capital capacities include self-organizing and regulating social systems that produce and evolve well behaved and self-regulating humane cultures, civil peace without repression, democratic institutions, fair and not overwhelmed justice systems, strong education, healthy human development, beauty, and peaceful relations among nations.

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