Reconciling Ecosystem Services with Neoclassical Economics

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> While economists [from about 1880 to 1970] ignored nature, ecologists pretended humankind did not exist. Rather than sully their science with the uncertainty of human affairs, they sought out pristine patches in which to monitor energy flows and population dynamics. Consequently, they had no political, economic - or ecological - impact.
>
> J. R. McNeill 2000: 336
> *An Environmental History of the Twentieth-Century World*

Abstract

Neoclassical economic theory, which has come to dominate much of the policymaking world, reduces the factors of production to labor and capital. Yet, the classical economists as far back as Adam Smith considered land to be perhaps the most important factor of production. The link between land - or more generally natural capital and ecosystem services - with the economy has effectively been severed by neoclassical economic thought. In that aftermath, both policymakers and academics understandably struggle to synthesize economic theory and the environmental sink in a systematic fashion. This paper is intended to serve as a policy guide that attempts to link economic theory with other issues that are either ignored or not yet synthesized into mainstream economic thought. (*JEL* A12, B10, E02, N10)

Introduction

Conventional economic models fail to incorporate a full picture of long-term drivers of economic activity and societal benefit. In the quest for a false sense of precision, the models have become ever more complicated and essentially incomprehensible to policy makers (Korinek 2015). Perhaps not surprisingly, the methodologically rigorous models are subject to wholesale modification and revision in the wake of a financial crisis.

A fuller picture of the drivers of the economy in the 21st century that includes more interdisciplinary and comprehensive approaches to understanding and monitoring would better benefit policymakers. Too many economics-related schools of thought have become disconnected from the physical world. Land, or more generally natural capital, figured prominently in the thinking of classical economists such as Adam Smith and David Ricardo. Starting in the 19th century, land was de-emphasized in favor of labor and capital as areas of primary focus. Monetary analysis also became more prevalent (Hubacek and van den Bergh 2006). In fact, mainstream economic training no longer requires study into properties of natural capital and ecosystem services relative to other areas.

Part of the dilemma is related to the role of the history of economic thought as opposed to economic history - two different subjects. The general belief that economic thought has evolved from classical political economy elaborated by Francois Quesnay (1694-1774) and Adam Smith (1723-1790) to more sophisticated forms such as neoclassical and neo-Keynesian may be misplaced. Recent events, such as the financial crisis of 2007-08, merely highlight the more general failure of economic policies based on a too-limited conception of the economy.

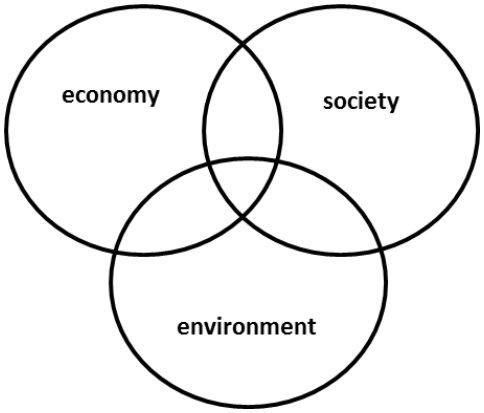
Neoclassical economic anomalies have come under scrutiny by behavioral economists such as Richard Thaler in an attempt to connect theory with what humans actually do in the real world. Even so, economists continue to favor abstract models. The resulting lack of robustness handicaps policymakers and is a disservice to society as a whole (Watson 2014: 19). Currently lacking is a more complete framework.

This paper is intended to serve as a policy guide that attempts to link economic theory with issues that are either ignored or not yet synthesized into mainstream economic thought, and bridge the gap between oversimplification on the one hand, and unmanageable complexity on the other. Further, microeconomic, macroeconomic, societal and environmental drivers remain compartmentalized from a policy perspective and would benefit from greater interdisciplinary approaches to analysis.

Environmental Sinks

Recent work suggests that the most important environmental issue that nations will face in the future is not availability of non-renewable natural resources, but rather the environmental sink - the ability of the earth to absorb waste and regenerate renewable resources (or ecosystem services). A closely related issue is what level of ecosystem services can be consumed at or below the regeneration rate of renewable natural capital. O'Hara (2015) argues that economic production functions are largely irrelevant outside societal and physical (environmental) contexts. Yet, too often the economy is interpreted as its own world, which merely overlaps periodically with society and the environment, as depicted in Figure 1.

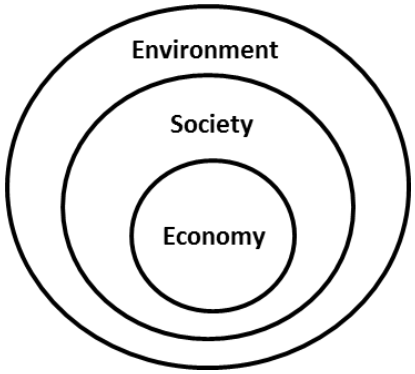
Figure 1. Partial Sustainability



Source: O'Hara 2015

Figure 2 more aptly demonstrates the position that economics occupies in the grand scheme. The economy is necessarily nested within natural and man-made systems. In addition, many economic-like activities occur outside of the purely economic sector and, as a result, do not show up as gross output. Such activities include household-provided goods and services, community support systems, or many aspects of ecosystem services derived from natural capital (O'Hara 1997). This paper attempts to develop a more comprehensive , yet concise, approach to economic policy than that offered by neoclassical or neo-Keynesian approaches.

Figure 2. Sustainability



Source: Kakovitch and O'Hara 2013: 6

Equation 1 below depicts a standard neoclassical production function. Neoclassical conceptions of the economy are linear and have largely abandoned the role of nature that was previously embedded in classical economics (Martins 2016). Neoclassical economics notoriously simplifies the classical economist view of the economy by assuming that natural capital (land) and built capital (capital) are perfectly substitutable, consistent with the weak sustainability approach. Thus, land is conveniently dropped from the production function, which simplifies matters considerably. Such a model is clearly a highly abstract way of depicting the factors that generate output for a given economy.

$$Y = f(K,L) \qquad (1)$$

where:

Y = output
K = capital
L = labor

More recently, dynamic stochastic general equilibrium (DSGE) models have been developed by central banks to attempt to capture the complex nature of modern economies from the bottom-up. These models seek to forecast not only a single quarter into the future, but also to an infinite time horizon. Such an approach requires approximations and computer simulations to solve even simple DSGE models (Korinek 2015). The mix of variables continues to shift as central bank economists attempt to refine the process, but examples include real GDP, private consumption, total investment, exports, imports, a GDP deflator, a consumption deflator, employment, nominal wages, nominal interest rate, real exchange rate, etc. However, conceptually important variables that are difficult to represent numerically are not included (Christoffel, Coenen and Warne 2010).

Despite the wide range of indicators used to try to forecast economic growth and the impact of shocks to general equilibrium, the ultimate weakness of DSGE models is the focus on the closed system of inputs and outputs, underpinned by the neoclassical belief that manmade capital can be substituted for natural capital (weak sustainability), and by extension for ecosystem services. The strong sustainability approach establishes a clear distinction between natural capital and built capital (Pelenc and Ballet 2015).

Prior to the 21st century, the use of a closed system could perhaps have been justified because the world was less crowded than it is now. Nonetheless, a more realistic approach was developed in the 1970s by Nicholas Georgescu-Roegen, which proposed variables that neoclassical economics neglects.

Equation 2 presents an expanded view of a standard production function that now includes the concept of entropy. The economy is in a continuous state of transforming low-entropy input (e.g., solar radiation, fossil fuels) into high-entropy output, part of which includes waste products. Considerations of entropy do not typically populate standard economic models.

$$Q_0^T(t) = F\,[R_0^T(t),\ I_0^T(t),\ M_0^T(t),\ W_0^T(t);\ L_0^T(t),\ K_0^T(t),\ H_0^T(t)] \qquad (2)$$

where:

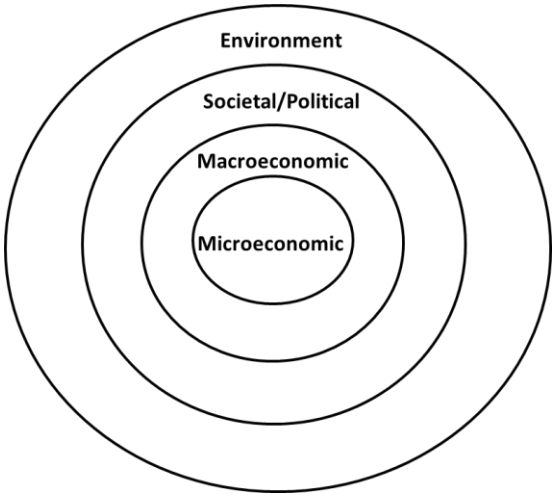
Q = output flow of products
R = natural resources
I = intermediate materials from other production process (e.g., lumber)
M = maintenance materials for existing capital (e.g., replacement parts)
W = waste
L = Ricardian land (capable of providing rents as described in classical economics)
K = capital (e.g., buildings and equipment)
H = labor
t = point in time
T = cumulative time periods under analysis

In equation 2, subscripts describe the interval under analysis, and superscripts indicate overall duration (Georgescu-Roegen 1971: 231-238). Although the model was developed in 1971, key components have yet to make their way into mainstream economic debate. In particular, M, W and T address issues of entropy that standard economic models omit.

Georgescu-Roegen's approach provides a more complete framework for inputs or flow elements that constitute the production process. For example, W (waste) is invariably treated as an externality and is thus exogenous to typical economic modeling. Yet it is properly integral to Georgescu-Roegen's model.

Figure 3 provides additional detail for sustainability diagrams presented earlier. In the case of societal/political and macroeconomic drivers, the Fed's charter essentially makes it responsible for three potentially conflicting goals: maximum employment, stable prices and moderate long-term interest rates. It is the social and political goals that thus drive macroeconomic policy. In turn, macroeconomic policies are intended to drive firm behavior, though not always as expected.

Figure 3. Elaborated Economic System



The macroeconomy is a subset of the ecosystem, dependent on the environmental sink to receive outputs of high-entropy matter-energy (Daly 2014: 41). While much emphasis has been placed on finite non-renewable resources, recent events such as the shale oil and gas revolution suggests that non-renewable resources may be less of an issue in the future (Sernovitz 2016: 50-58) than the capacity of the sinks in which they are deposited.

The environment ultimately limits what options humans have available. The environment - or ecosystem services - limits lifestyle and governance choices. Of course the causality can certainly run both ways. Hunter-gatherer societies evolved into farming societies, along with their attendant bureaucracies where the land was suitably fertile. However, through ecosystem service depletion and degradation, societies can forestall the growth of hierarchies made possible by surplus, and in turn be forced to revert to societal structures that resemble hunter-gatherers once again.

Since its inception, macroeconomic theory has never come to terms with the prospect for anything other than continuous growth. In his classic work, for example, Milton Friedman developed the constant money growth rule, where the money supply grows at a constant rate forever (Williamson 2016). Yet credible forecasts suggest that population growth worldwide is set to peak and perhaps begin to decline in the middle of this century (Robbins and Smith 2016).

Development of economic thought to-date has traditionally relied heavily on inductive approaches to theory - in essence, by developing general rules too readily from limited numbers of specific cases. Going forward, economics will rely more on deductive approaches based on evidence from the real world using more systematic evidence, and paying attention to what humans actually do, as opposed to what economic theory says they should do (Thaler 2016: 352). Behavioral economics, for example, is a natural progression that incorporates a more robust framework for developing public policy into neoclassical economics (Chetty 2015).

Gordon's Inflection Point: 1870

As mentioned earlier, economic history and the insights it can provide have been largely subordinated to the history of economic theory. This has led to the development of clean and symmetrical economic models that very often, unfortunately, do a poor job of describing or predicting the real world.

By incorporating patterns that can be derived from a more systematic look at the panorama of economic history we can better understand why so many economic models fall down on the job. In particular, the history of economic thought and technological development that derives from its origins is relatively short. The study of economics dates back only to Quesnay (1694-1774). Just a century later, around 1870 with economics still in relative infancy, unprecedented change began to take place that had implications for society and the environment which remain underappreciated.

Robert Gordon notes that essentially no economic growth occurred in the eight centuries between the fall of the Roman Empire and the Middle Ages. From 1300-1700, things were only marginally better, when real output per person in Britain only doubled over that 400 year interval. By contrast, during the twentieth century in the U.S., output per person doubled every 32 years.

Gordon's ultimate thesis is that the inventions and innovations in terms of quality of life between 1870 and 1970 were transformative in an unparalleled fashion, with significant implications for the twenty-first century. Of particular note is the fact that the transformation which occurred in the U.S. and most of the developed world cannot be repeated. Those gains have been taken and future productivity increases will be dependent on other new innovations.

A significant part of the increase in standards of living, equality and economic productivity was the result of the networked home and business - something unheard of in all the previous centuries of human existence. These networks consisted of five components that are all too familiar now, and yet to which modern economies are oddly disconnected from or even oblivious to, short of some natural disaster that disrupts them: electricity, gas, telephone (which now includes the internet), water and sewer (Gordon 2016). Most residents of developed countries live far better than kings and nobles just two centuries ago. Yet, this too is often forgotten in the hustle-bustle of consumer society that increasingly taxes ecosystem services through escalating depletion and degradation.

A whole host of inventions and innovations that constitute routine aspects of urban planning - which defines in large measure how we live today - did not become widely available until the early twentieth century. It's worth noting here, for example, that the term infrastructure dates back only as far as 1875. There were no U.S. corporations in 1870, and the average factory at the time employed less than ten people (Higgs 2014: 167).

The first age of globalization began in the 1870s with export-led growth in commodities from developing countries to the industrializing Western world (Scheidel 2017: 379). As the scale of industry and cities increased, new theories were developed in an attempt to explain them. Neoclassical economics traces its roots back to the 1870s (Blaug 1985: 294-295; Gómez-Baggethun, et al. 2010). For simplicity and due to the assumption of substitutability of natural capital with built capital, after about 1880, Anglo-American economists took nature out of economics altogether (McNeill 2000: 336), as explicitly postulated by Robert Solow (1974).

Another example of progress that substantially raised standards of living was the germ theory of disease. While the theory was first proposed in 1546, it wasn't until the 1870s that Joseph Lister developed practical applications for sanitation in medical settings, thus setting the stage for increased average longevity. The other two key developments that had huge increases in life expectancy were marked decreases in infant mortality, and the use of antibiotics. Since then, virtually all medical innovations have been highly incremental in nature for society as a whole in terms of increased longevity.

Other examples abound of how unusual the great inventions of the late 19th and early 20th century were. The prototype electric kitchen exhibited at the 1939 World's Fair looks remarkably like modern kitchens (Ziegelman and Cole 2016: 267-269). Air travel by jet was introduced in the 1950s and has not improved significantly since (Vijg 2011: 55-57). And travel by automobile has improved only incrementally since the earliest days of mass production.

Marc Levinson makes the case that the Golden age of productivity growth between 1948-1973 is giving give way to a prolonged period of ordinary economic performance (Levinson 2016: 28-55). Indeed, all of the above events occurred near the end of the most technologically dynamic epoch in the United States (Field 2011: 312-313). These developments suggest that western economies may be experiencing an extended period of limited total factor productivity growth.

Perhaps most significantly, measures of happiness in the developed world have not improved noticeably in the past 50 years since the widespread adoption of the five network connections identified above (Clark, Frijters and Shields 2008; Diener and Biswas-Diener 2002; Easterlin 1995). Increasing wealth no longer appears to increase happiness and well-being (Diener and Seligman 2004; Smith, et al. 2013; Kubiszewski, et al. 2013; Klein 2014: 60; Skidelsky and Skidelsky 2012: 102-107).

Generally speaking, a happy life requires relatively few straightforward elements and is similarly defined by several authors. Methods used to describe a full or satisfying life include as few as four basic components: family, community, faith and vocation (Murray 2013). Maslow identified five needs: physiological, safety, love, esteem, and self-actualization (Maslow 1943). Skidelsky and Skidelsky (2012: 154-167) list seven aspects: health, security, respect, personal autonomy, harmony with nature, friendship, and leisure. However one may be inclined to quibble with the definitions, what is clear is that most of the developed world has access to all of them. Yet a consumer-oriented society still drives people to clamor for more, irrespective of concerns about environmental sustainability.

Haber-Bosch as a Precursor

One of the best examples of how the late 19th century technology began to change economics as never before is the manner in which mankind overcame global population limits of about 4 billion people. At that time, Peruvian guano deposits use for agricultural fertilizer had already been exhausted, and natural nitrate deposits from the Atacama Desert in northern Chile were rapidly being consumed. As a result, a warning was sounded in 1898 by the incoming president of the British Academy of Sciences, Sir William Crookes. In addressing the audience, Sir Crookes made the pronouncement that large numbers of the population, particularly in the advanced nations would begin to starve to death sometime around the 1930s. This would occur even if every available acre of arable land on the planet was cultivated - unless something was done soon.

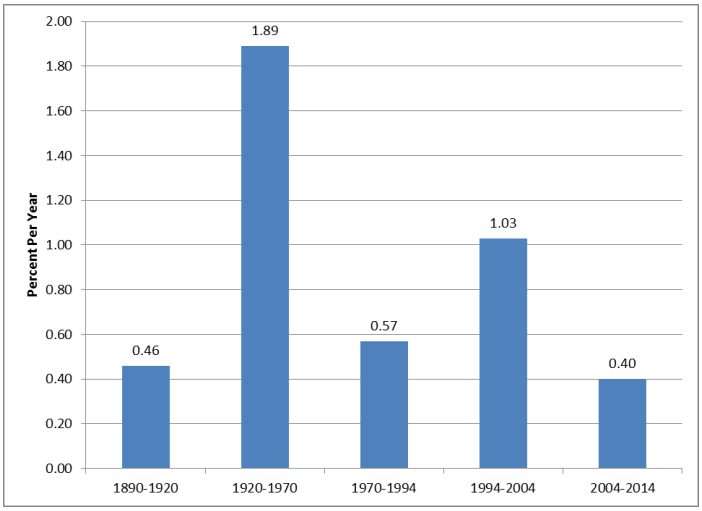
Of course, the prediction of mass famine did not materialize, and both the reasons why as well as the follow-on impacts are instructive. Using previously unavailable combinations of materials, extreme pressures and electric energy that had only become widely available starting in the late 1800s, Fritz Haber and Carl Bosch developed the technology to producer manmade fertilizer on a mass scale in 1910. Had the hitherto unimaginable Haber-Bosch process not been developed, food production would have limited world population sometime in the mid-twentieth century. By converting atmospheric nitrogen (N_2) into fixed nitrogen, enough fertilizer can now be produced to grow enough food to support over 7 billion people. Ironically, instead of famine, many parts of the world now struggle with an epidemic of obesity (Hager 2008).

The unexpected bounty of manmade fertilizer has made concerns about food shortages more or less irrelevant. Instead, the salient issue associated with widespread use of industrial fertilizer centers on the issue of runoff from agricultural regions into rivers, lakes and oceans that have become sinks for waste and are creating dead zones deprived of oxygen, one of several factors that combined may result in abrupt environmental change regionally and globally (Rockström, et al. 2009). The ability of the earth's environmental sink to continue to absorb all manner of industrially produced wastes and still continue to provide ecosystem services essential for human and animal life is reaching a critical juncture.

U.S. Total Factor Productivity Peak

Figure 4 shows how the U.S. experienced an unprecedented - before or since - surge in total factor productivity (TFP) in the 1920-1970 timeframe (Figure 4). This more recent explanation is more granular than most other studies, which tend to look at the 20th century as a whole.

Figure 4. Annualized Growth Rates of Total Factor Productivity (1890-2014)



Source: Gordon 2015: 575

Alexander Field (2011) undertaking similar research tells the essentially the same story. The largest increases in TFP occurred in the first half of the 20th century, and while periodic fluctuations have occurred, overall decline has been steady. As ongoing declines in total factor productivity appear to manifest themselves in a variety of industries, it will be worthwhile to examine the prospective implications, both positive and negative.

Macroeconomic Policy Failures

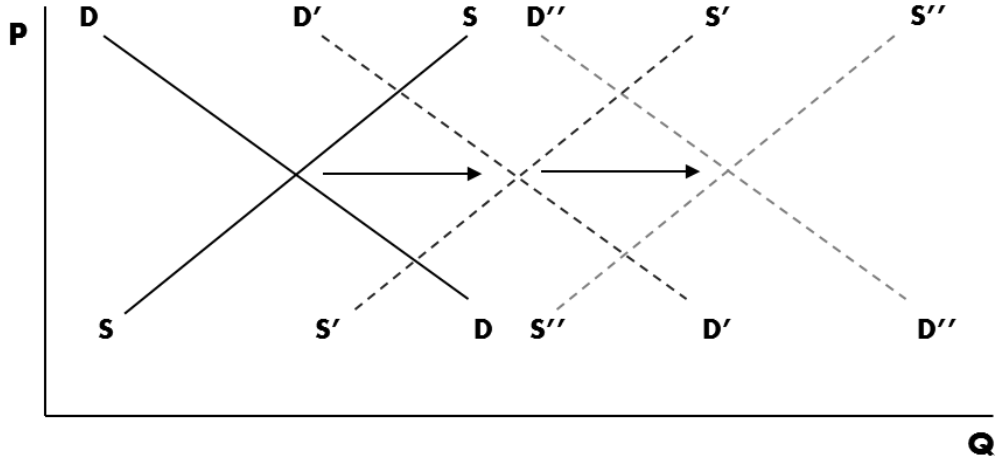
Neoclassical and neo-Keynesian economics - both of which now influence central bank thinking in one way or another - typically look for intricate, mathematically rigorous solutions that, at the same time, simplify assumptions in order to achieve some state of equilibrium. These models are both abstract and complicated - essentially a black box to policymakers. With so many moving parts in a modern economy, it is fair to ask how legislators and government officials can be cognizant of all the macro-drivers/issues that necessarily should be incorporated into a comprehensive decision making process.

To be sure, criteria outside the models appear to be on the mind of the Federal Reserve, though it is not clear what powers it has to address them. In a 2016 speech, Fed Chair Janet Yellen touched on concerns about the level of output in the U.S. economy, specifically mentioning aging workforce, smaller gains in productivity, decreased propensity to spend, and a lack of attractive capital projects (Yellen 2016).

In the meantime, using the explicit tools granted by statute, the Federal Reserve sought to achieve higher levels of producer and consumer price inflation. Instead, however, it has likely ushered in dangerously high levels of asset inflation. Figure 5 depicts what the Fed actually achieved, which increases the quantity of goods produced, but has a muted effect on consumer price inflation. Economic activity on both the supply and demand side have been artificially stimulated and brought forward, but not in a sustainable fashion.

In attempting to bring consumption forward, the Fed appears to have been successful, as evidenced by increased housing prices and car sales spurred by low interest rate financing. Yet, by way of analogy, the Fed is simply doing what many companies do at the end of the month or the end of the quarter: booking sales to dress up income or earnings statements. But bringing forward revenues doesn't increase overall sales - it just changes the timing of when they are recognized.

Figure 5. Federal Reserve and Aggregate Supply/Demand



In more recent and desperate attempts to stimulate consumption, central banks began to experiment with negative interest rates. From a global standpoint, interest rates in 2016 were at record lows — going back 5,000 years (Haldane 2015).

While negative rates were intended to encourage consumers to spend, the policy move instead appears to have had the opposite effect in Japan and Germany. Faced with extremely low or negative interest rates, consumers believed they needed to save even more to fund retirement. People saved more instead of spending, thus impeding the intended economic stimulus.

Low interest rates in the U.S. intended to spur consumer spending and achieve higher levels of consumer price inflation have instead inflated asset values. Low interest rates simply drove investors into stocks and other more speculative securities.

Central banks around the world are essentially trying to encourage consumers to spend or borrow money instead of saving it. Perhaps these macroeconomic planners should consider that other factors, such as demographics, may have substantially altered consumer spending patterns for years or decades.

Indeed, the Great Recession caused a fundamental shift in the way consumers evaluate estimates of their lifetime income and, similarly, how much they need to save for retirement. This is particularly true in light of prolonged low or even negative interest rates. Economist Robert Gordon has recently suggested that for a variety of reasons, productivity in the U.S. will grow more slowly than many have anticipated — something the Fed is powerless to address.

None of these actions — explicitly encouraged by central bank policy — suggest a recipe for long-term economic and societal success. Central banks failed to factor in the radical uncertainty of the future that consumers and savers face – essentially that their old narrative or paradigm about how the world is structured was been revised downward.

There are other factors that make current Fed policy ineffective, even destructive. China and Germany, for example, have export-driven economies that have created unsustainable structural imbalances. Instead of exporting so heavily, these countries should be trying to develop domestic demand in their own markets. The Fed policy of encouraging U.S.-based consumption does nothing to address this issue (King 2016: 324-328).

For publicly-held corporations, Fed-induced financial engineering encourages cheap borrowing that could be used for investment. Yet instead of capital spending on research and development, the bulk of this debt has been used to fuel stock buybacks and dividend payments. The failure of economists and the Fed to fully incorporate a larger perspective into models and frameworks increase the incidents of booms and busts. Specifically, global overproduction, coupled with leveling demand growth further drove down interest rates.

Microeconomic Fallout

One of the most dubious schools of thought that emanates from economic principles combines agency, property rights and finance theory into a model of the business firm (Jensen and Meckling 1976). Since the popularization of the theory of maximizing shareholder value (MSV) took hold in the 1980s and 1990s many corporations jettisoned almost all other considerations. The benefit to society of maximizing shareholder value to the subordination of all else is increasingly being called to task.

MSV represented a significant shift in corporate culture. Johnson and Johnson's Credo, for example, was formulated in 1943 and begins with their first responsibility, which is to the doctors, nurses and patients, mothers and fathers and all others who use their products. In other words, their customers. J&J's

suppliers and distributors are mentioned next, along with a reference to their opportunity to make a fair profit. Then employees. Then communities. Only at the end of the credo are the stockholders mentioned, where they are promised a fair return.

The change in culture has caused Nobel prize winner Edmund Phelps to openly question whether senior executives now care more about building their dream homes than building their companies (Phelps 2013: 323). As members of an increasingly complex society, corporations have an obligation to a broad range of stakeholders. Indeed, corporations that consistently act in a socially responsible way are able to accrue goodwill that can benefit them later (Godfrey, Merrill and Hansen 2009).

Yet developments trended the other way after the Great Recession and macroeconomic policies did much to set the stage. According to Laurence Meyer, low fed fund interest rates should encourage firms to issue equity to pay for additional business investment (Meyer 2004: 43-45) and this was certainly the intent of central banks. For publicly-held corporations, Fed-induced financial engineering did in fact encourage cheap borrowing. However, instead of capital spending on research and development, the bulk of the debt was used to fuel stock buybacks and dividend payments, which inflated asset prices. With few apparently good opportunities for investment that will pay off in the *near* future (when stock options and incentive pay vests) corporate executives resorted to stock buybacks and dividends to maintain share prices. From the end of the Great Recession through 2016, corporations paid out more than 100% of earnings to shareholders, with the difference made up from inexpensive borrowing, selling assets, tapping cash reserves or through layoffs (Lazonick 2016).

The result of macroeconomic policies intended to move the economy forward instead exacerbated income inequality that began with the peak of total factor productivity growth in 1970. The largest impact of income inequality in the U.S. has come as a result of executive compensation in the top 1% in large financial and nonfinancial corporations (Piketty and Saez 2015).

By lowering interest rates and making credit readily available to large borrowers, the Fed accelerated a trend that started in 1982, when the SEC allowed stock repurchases by the issuing companies (Lazonick 2016).[1] Since then, corporations have used a large portion of earnings to buy back their own shares and pay dividends, often at the expense of investing in long-term capital projects and even while stock valuations were high by historical standards.

Economy and the Environment

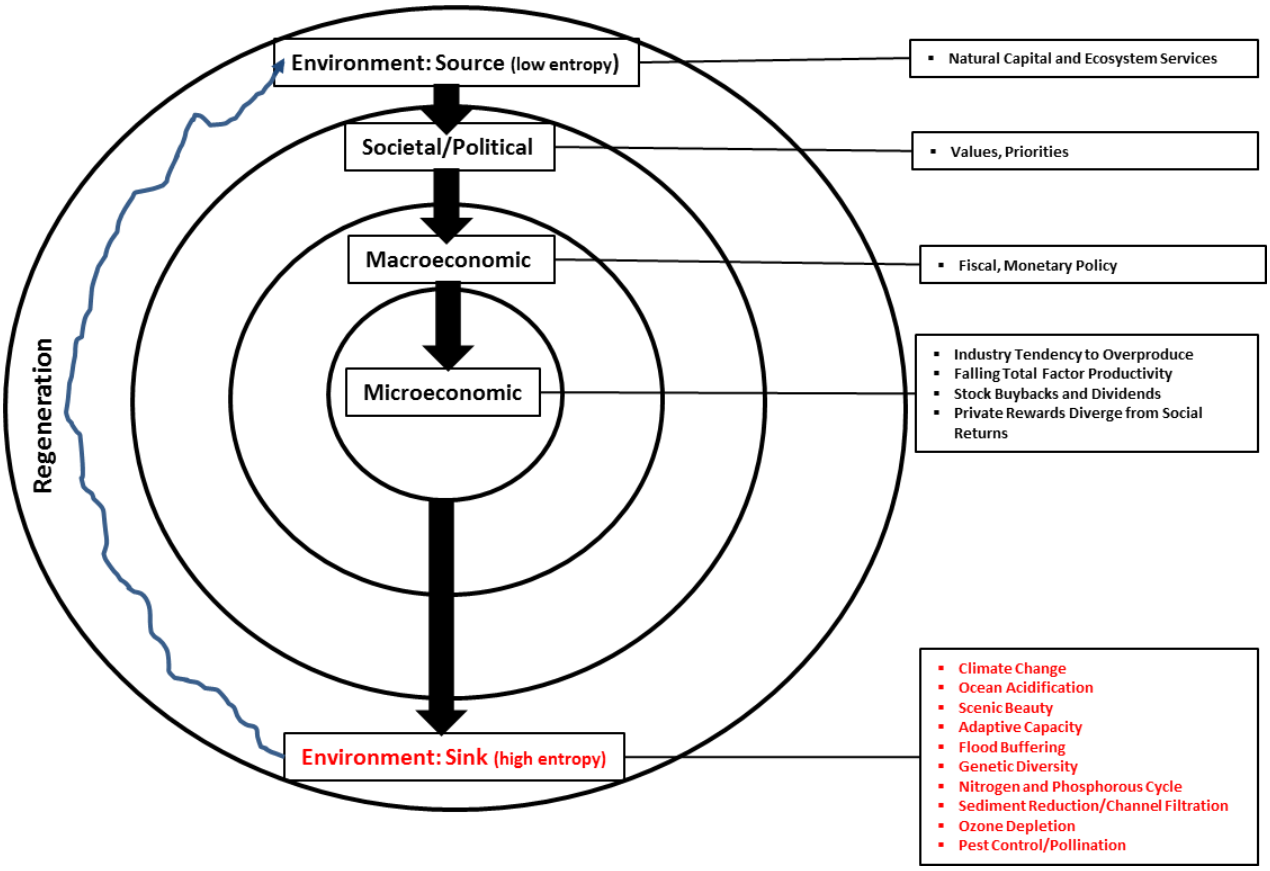
Spurred by macroeconomic policy and dubious theoretical underpinnings, corporations continue to maximize shareholder value at the expense of larger societal concerns and other stakeholders. Underpriced natural capital and ecosystem services remain the key casualties. Despite efforts to encourage firms to internalize costs that are typically treated as externalities, progress remains mostly voluntary (Chouinard, Ellison and Ridgeway 2011). The environmental sink suffers as a result.

What is needed is a more robust picture of the components of a modern economy. Figure 6 outlines a fully elaborated economic system that is not adequately reflected in textbooks. The diagram explicitly acknowledges the environmental and societal, in addition to both the macroeconomic and

[1] SEC Rule 10b-18, which provides a safe harbor to corporations from charges of stock-price manipulation on open-market purchases meeting certain requirements.

microeconomic factors that impact the environmental sink, and the ability of the earth to regenerate ecosystem services.

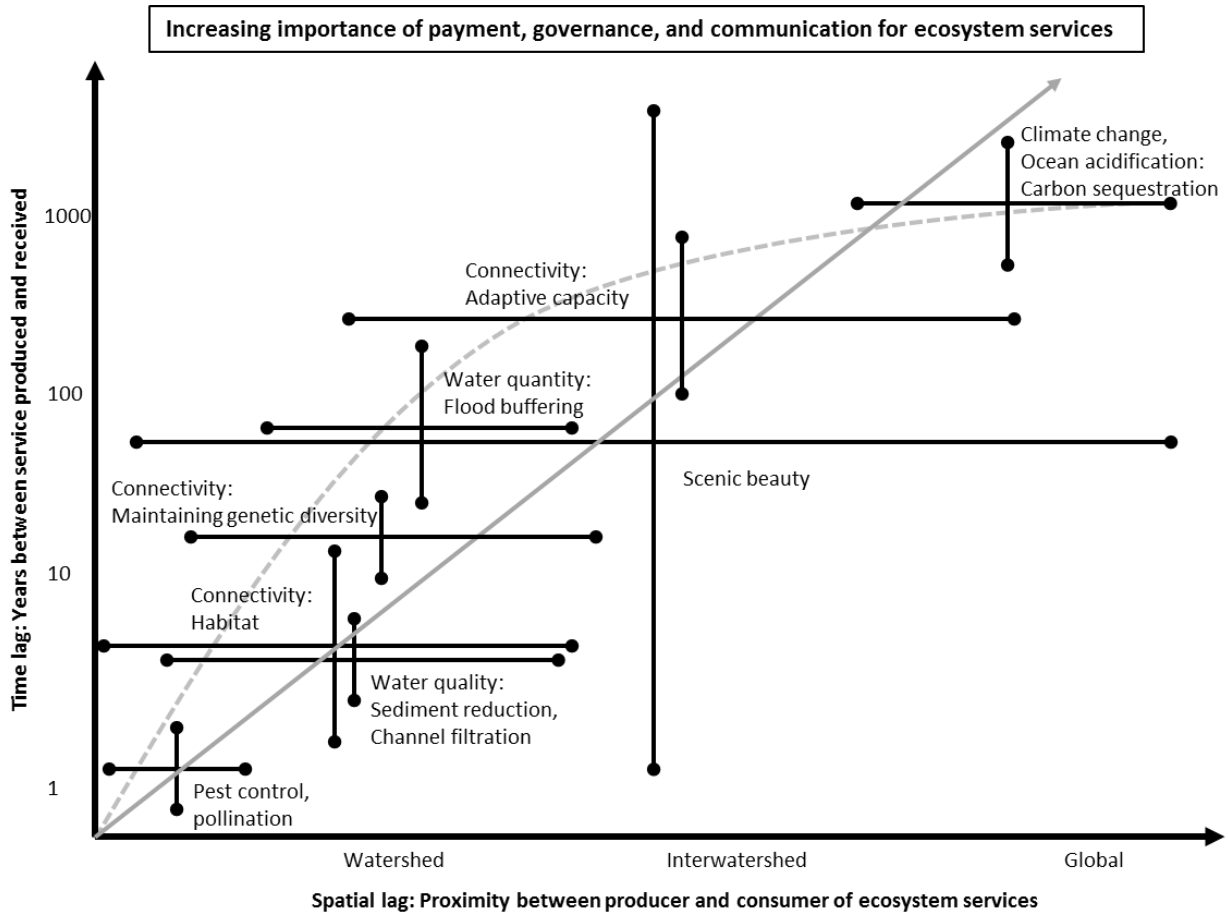
Figure 6. Fully Elaborated Economic System



Part of the challenge of understanding environmental issues and priorities is the fact that they vary in terms of affected geography (Ramirez, Mukherjee, Vezzoli 2015) and timescales to regenerate. Lumping environmental issues into a single basket does little inform policy understanding. Figure 7 highlights spatial and temporal scales for a sampling of ecosystem services. The most significant and difficult to remedy ecosystem services occur on a global scale and may require hundreds of years to regenerate.

In addition, it is important to note the distinction between built or manufactured capital, and renewable natural capital. Discounting built capital (typically referred to simply as capital) occurs because it has a limited useful life. By comparison, discounting natural capital would be similar to the notion of depreciating real estate, neither of which recognizes appreciating value. Further, it may make sense for a mortal man to discount the future, but mankind is quasi-immortal and so discounting natural capital makes no sense. Indeed, policy relative to future generations should be less about maximizing utility and more about minimizing environmental regrets (Georgescu-Roegen 1977). At the end of the day economics is a biological system, not a mechanical one. The issue to often overlooked by economists is that economic systems are not outside of nature - they are, in fact, part of the ecosystem (Martins 2016; Raine, Foster, Potts 2006).

Figure 7. Effective Management of Ecosystem Services - Lags Between Production and Consumption.
(Solid gray line indicates increasing importance of management/payment for ecosystem services. Dotted gray line suggests spatiotemporal trade-offs of sink functions and ecosystem services.)

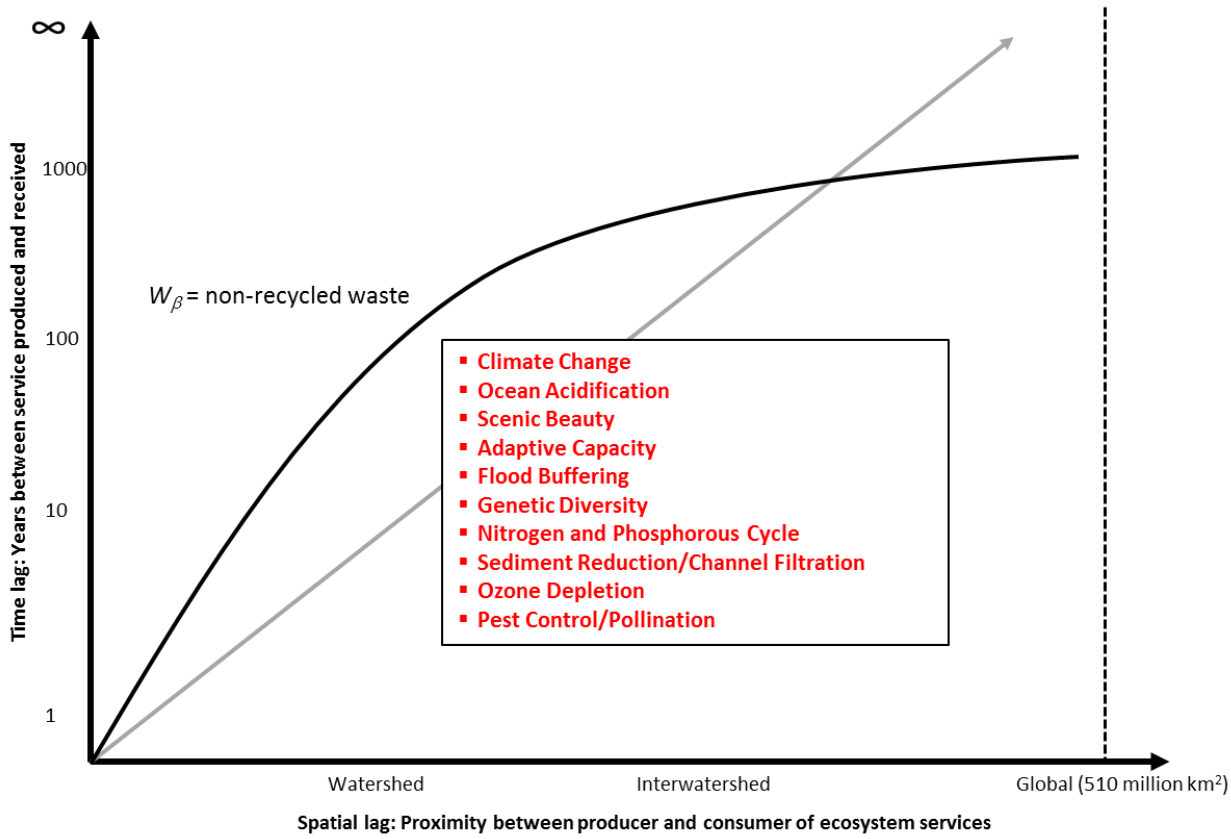


Adapted from Fremier, et al. 2013

The levels of complexity associated with ecosystem services goes well beyond the classical economists and figures nominally, if at all, in neoclassical theory. Yet natural capital and ecosystem services are deterministic drivers of human economic activity that largely continue to be depleted and degraded (Diamond 1999: 439). Without critical ecosystem services, humans and animals cannot survive.

Extending the analysis, Figure 8 maps the implied spatial/temporal curve of ecosystem service regeneration based on analysis by Fremier et al. (2013), which suggests that as spatial scale of impact increases, temporal scales increase much faster - up to a point. In other words, the larger the geography impacted by waste entering the environmental sink, the longer the period required for ecosystem service regeneration. The curve suggests that perhaps after 1,000 or so, most manmade problems can be reversed by planetary systems.

Figure 8. Implied Curve of Trade-Offs Between Temporal and Spatial Scales



The accumulating impact of non-recycled waste on ecosystem services suggests the prospect of a revised production function that draws a distinction between natural capital and built capital (Equation 3). Natural capital stocks have been replaced by ecosystem services flows. Non-recycled waste is also explicitly included, as this poses a potential limit to the provision of ecosystem services. Built capital (K_B) represents the flow of services from depreciating assets during their useful lives.

$$Y = f(E, K_B, L, W_\beta) \qquad (3)$$

where:

Y = output
E = ecosystem services
K_B = built capital
L = labor
W_β = non-recycled waste

W_β must be absorbed by the environmental sink, which taxes the ability of natural capital to regenerate and provide ecosystem services. As W_β approaches the limits of the sink, ecosystem system services begin to degrade with increasing acceleration. Where these points are reached - depending on geographic scope of the ecosystem service in question - remains a topic of ongoing research.

Since ecosystem services are derived from natural capital, then $E \in K_N$, where K_N = natural capital. Waste is a byproduct of industrial processes, whether recycled or non-recycled, and as such are elements of built capital: $W_\alpha + W_\beta \in K_B$, where W_α = recycled waste. The waste accumulation curve in Figure 8 follows the general form of exponential increase to a limit: $y = ae^{bx} + c$. The non-linear, in fact exponential nature of the curve implies a policy goal of $W_\beta = 0$ in order to ensure strong sustainability in the face of future uncertainty regarding the valuation of natural capital and the corresponding ability of ecosystem services to regenerate after absorbing non-recycled waste.

Figures 9a through 9c illustrate hypothetical spatiotemporal distributions of environmental events as a result of industrialization that impact the sink and degrade ecosystem service functions. Figure 10 represents the spatiotemporal distribution in present day. Specific examples of environmental impacts and their spatiotemporal position are outlined as well.

The distributions assume that the more numerous impacts tend to be local and can be remediated in shorter timeframes than larger scale impacts such as climate change and ocean acidification. From a public policy standpoint, there has been a failure to develop a comprehensive framework of the type depicted in Figure 10 that visually portrays the numerous, disparate impacts of non-recycled waste on the environmental sink, and thus contributes to the general lack of awareness of the range of accumulating pressure on natural capital to regenerate ecosystem services.

For many manmade environmental impacts, or what economists refer to as externalities, systematic tracking does not yet exist, so the distributions are merely hypothetical illustrations. Nonetheless, they are instructive in that they establish a comprehensive picture of range of strains on the earth's sink. Another key point is that the interactions as a result of increased complexity are not well-understood. Feedback effects from increasing numbers of environmental events have the potential to create unexpected and unintended consequences. In this regard, humans are in uncharted territory.

Central bank attempts to stimulate growth through macroeconomic policy, irrespective of strains on ecosystem services that undermine long-run sustainability, or corporations that seek to maximize shareholder value, devoid of virtually all other considerations, are both bumping up against diminishing returns. A full reassessment of macroeconomic and microeconomic theory will be required in order to assure the adequate provision of ecosystem services necessary to support a planet with 10 billion people in the 21st century.

Figure 9a. Accumulating Environmental Impacts Over Time (Figs. a-c)

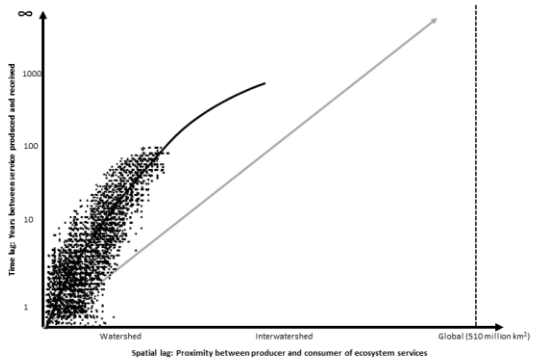


Figure 9b.

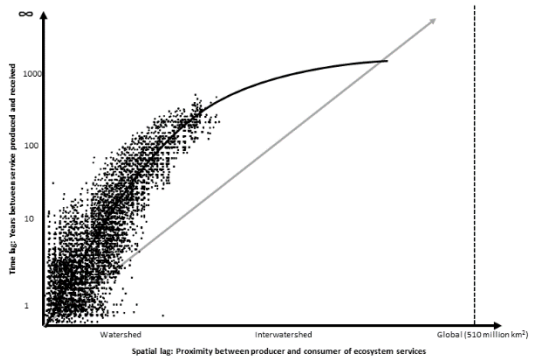


Figure 9c.

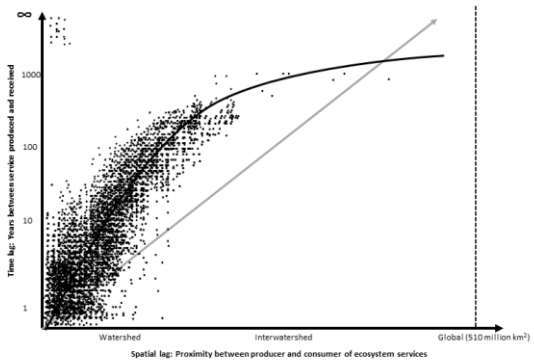
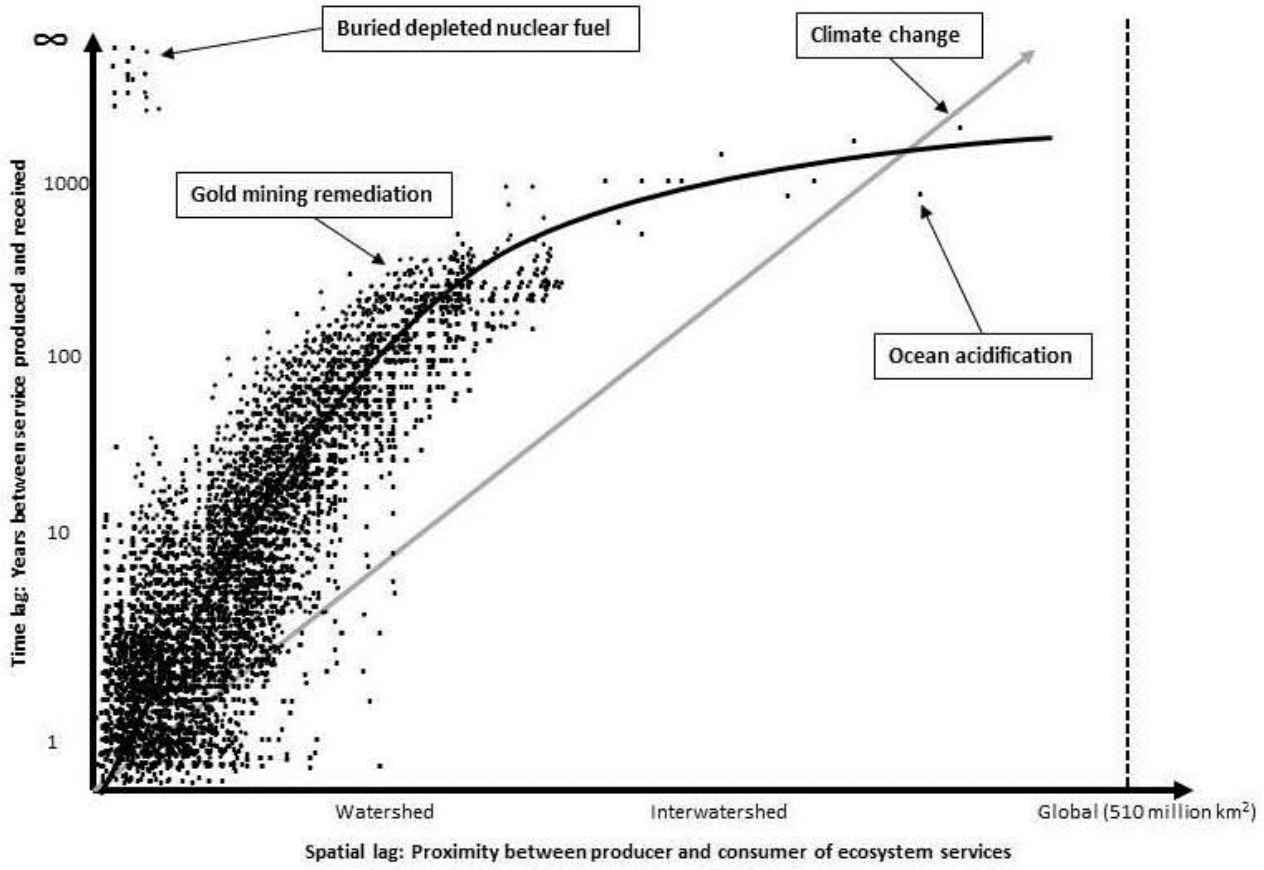


Figure 10. Hypothetical Present-Day Distribution of Impacts to the Environmental Sink



Environmental Early Warning Indicators

Global warming tends to dominate much of the debate regarding environmental costs associated with industrialization. However, the reality is that a whole host of environmental issues face societies, some perhaps more critical than global warming (Rockström, et al. 2009). Looking back over the long sweep of human history, local ecosystem collapse is typically driven by five factors: environmental damage, climate change, hostile neighbors, trade disruptions, and societal collapse. The time period from peak to total collapse can be very brief (Diamond 2011: 11-15).

The world has witnessed political situations which start as an environmental effect, such as the Syrian drought, but then escalate into civil war prompted by the lack of food, loss of livelihoods and poor governance (Kelley, et al. 2015). Environmental issues are likely to be the proximate cause of future social upheaval as well. As such, early warning indicators for ecosystem services, which can take a variety of forms, will be more crucial to understand than ever before.

While some ecosystems degrade in a continuous fashion, others evince non-linear characteristics (Farley 2012). These systems may demonstrate a critical slowing down, a skewness, or flickering. These initial indicators can then be followed by bifurcation, where the system appears to be recovering, only to revert, transition and perhaps even collapse altogether (Sheffer, et al. 2009; Sheffer, et al. 2001).

In the case of decreasing biodiversity, signals can be presaged by loss and displacement of slowly replicating and weakly competitive "canary" species with slowly replicating but strongly competitive "keystones." Collapse of keystone species can result in their replacement by weakly competitive but fast-replicating "weedy" species (Doncaster et al. 2016). Taken to an unpalatable extreme, one might imagine a planet populated largely by highly adaptive species such as rats and sharks (McNeill 2000: xxii-xxiii), with perhaps the short list of five large animals (over 100 pounds) that humans have successfully domesticated: sheep, goats, horses, cows and pigs (Diamond 1999: 153)[2].

Terrestrial systems that could be early warning indicators for global climate change include the Arctic sea-ice, the Greenland ice sheet, and the Sahara/Sahel and West African Monsoon (Lenton et al. 2008). Another recently measure is a global vegetation sensitivity index that has been developed to identify areas sensitive to climate variability (Seddon et al. 2016).

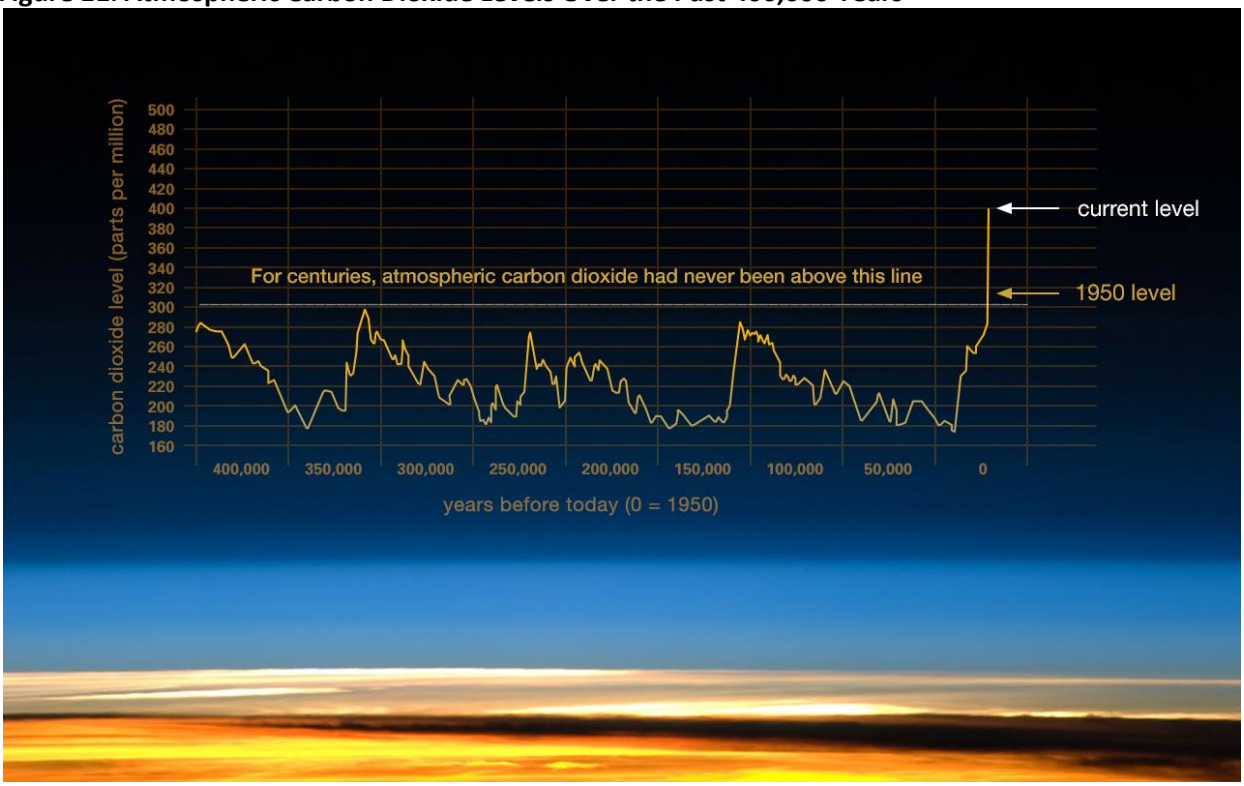
Of course, early warning indicators are of little use if no one heeds them. A key challenge impeding a more comprehensive picture of economic theory and public policy is civic perception. Gallup polls, for example, show that the general public is far more interested in overall economic performance or its dissatisfaction with government. Environmental concerns fall below issues such as national security, education and healthcare (Gallup 2016).

Humans have in a relatively short period of time reached the point where they can match or even dominate the great forces of nature (Steffen, et al. 2007). Since 1870, human ability to alter the environment and disrupt necessary ecosystem services is without precedent. Put simply, humans don't live on the frontier anymore (Hacker and Pierson 2016: 76).

Perhaps most salient is that resource scarcity may not be the limiting factor on traditional economic growth. Instead the key constraint may turn out to be the finite ability of the planet to absorb human waste products (O'Hara 2015). Based on data from NASA, Figure 11 highlights how atmospheric CO_2 levels have risen to unprecedented proportions - going back 400,000 years - even as the ultimate impacts remain highly uncertain.

[2] Diamond includes nine other minor species that have been domesticated in limited areas of the world: Arabian (one-humped) camel, Bactrian (two-humped) camel, llama/alpaca, donkey, reindeer, water buffalo, yak, Bali cattle and mithan (Diamond 1999: 153-154).

Figure 11. Atmospheric Carbon Dioxide Levels Over the Past 400,000 Years



Source: https://climate.nasa.gov/evidence/

The Promise of the Developing World

Neoclassical belief that the economy can expand indefinitely into an essentially infinite universe might have turned out to be (and may yet become) a workable concept had space travel become as commonplace as envisioned. The idea of earth travelers routinely visiting nearby planets, asteroids and stars once seemed a near certainty based on the work of science fiction writers featured as far back as 1865, when Jules Verne wrote *From the Earth to the Moon*. H.G. Wells penned his first novel in 1895, and the serialized science fiction publications such as Amazing Stories began to appear in 1926. But space travel and many other engaging technologies turned out to be more problematic puzzles to solve than first believed. As another example of unfulfilled technological optimism, the Mr. Fusion device powering Dr. Emmett Brown's DeLorean in *Back To The Future* - fed by discarded trash: banana peels, stale beer, and aluminum cans - appears to be a long way off as well.

In the case of human lifespans, any upturns on the scale accomplished between 1870 and the end of the 20th century (an increase of 33 years for the average person) appear unlikely (Gordon 2016: 50). So many of the future breakthrough technologies envisioned in the early part of the 20th century have failed to materialize, in contrast to the way transformative inventions such as electricity, motorized vehicles, and motion pictures did in the latter part of the 19th century.

Of course, incremental improvements will certainly continue. And perhaps with sufficient increases in government and industry-sponsored research and development, economies may even enter another age of rapid total factor productivity growth in 50 or 100 years from developments into such areas as

commercial space exploration, gene therapy, full-functioning robots, and fusion energy. But none of these advances appear to be on horizon.

According to Robert Gordon, it is very possible that modern economies will undergo a period of relatively slow total factor productivity growth, which contrasts starkly with TFP growth that occurred in the hundred years after 1870. That period marked the introduction of many innovations - in particular two key general purpose technologies: electricity and the internal combustion engine, which could only happen once. Productivity increases resulting from the great inventions have since been absorbed. For the present and foreseeable future, total factor productivity growth will likely remain flat (Gordon 2016: 555-608).

In the absence of game-changing technological advantages, maintaining the infrastructure that supports the quality of life achieved over the 20th century will dominate public policy discussion. Rebuilding the aging US infrastructure as proposed by the Trump administration, for example, only maintains current living standards. From a functional standpoint, reconstructing or upgrading existing infrastructure does nothing particularly new.

The best prospect for global growth and productivity, as well as greater global equality, now appears to lie with key infrastructure projects in developing economies (Collier and Venables 2016). Providing the five network connections essential to a basic standard of living to homes and businesses would enable developing countries to obtain the increases in productivity that developed countries have enjoyed for a century.

Such a policy move is consistent with the UN's Millennium Project goals and would go a long way toward tempering the developed world's export of environmental degradation to countries that have little to offer world markets beyond agriculture, fisheries, and forest products (Rees 1992). Because poorer and less well-educated societal groups tend to be less sensitive to environmental impact of economic activities (Zheng and Kahn 2017), providing the basic standards of living would tend to assuage pressure on ecosystem services where it is most acute.

This paper posits that the world has reached the point where, for the foreseeable future, the overriding goal of developed nations will be to simply maintain the standard of living achieved over the past century and a half. If true, such a controversial paradigm begins to answer the question of what new jobs in the future will look like.

In the broadest terms, many people will be employed to maintain sufficient regenerative capacity in ecosystem services necessary to provision a global population of 10 billion or more. There will be ample opportunity for increases in research and development into nascent areas such as fusion power and gene therapy, though public policy in this direction remains uncertain. Depending on the speed of planetary warming and the impact of climate change, resilience and mitigation planning will engage large segments of the workforce as droughts, hurricanes, typhoons and other events become more prevalent. These will be important jobs that will certainly challenge human intellect and creativity, but again at best serve to maintain existing standards of living.

Future Policy Implications

What may come as a surprise to many is that world population is set to level off somewhere between nine and twelve billion people between 2050-2070, and then almost certainly begin to decline -

assuming the planet can continue to sustain such large numbers until that time (Robbins and Smith, 2016). Upcoming demographic shifts will have significant implications for elderly care, traditional rural labor surpluses from developing countries and future population migration patterns. Continued global migration, for example, will enable developed countries to address declining population.

Another issue that classical political economy or a more ecologically-oriented view of economics will be better able to address has to do with the tendency of industrial economies tend to overproduce - whether capitalist, communist, socialist, social democratic, or capitalist communist. Oversupply of commodities - agricultural products (e.g., beef, dairy, eggs) or copper and oil, or housing - have frequently caused price deflation. All industrialized economies have regularly demonstrated the ability to become efficient and overproduce. This propensity to overproduce is partly a function of ever more efficient automation, but also stems from the ability of firms to utilize "free" ecosystem services and natural capital that are underpriced relative to long-term value. Current price mechanisms for ecosystem services simply do not reflect full replacement costs. Preliminary work has been undertaken that demonstrate the value-added ratios using current pricing for industrial activities such as solid waste combustion, coal-fired electric power generation, and sewage treatment are negative from an air quality standpoint alone. A full set of environmental accounts would encompass not only air, but also water pollution, solid waste, and hazardous waste as part of the national economic accounts system (Muller, Mendelsohn, Nordhaus 2011).

The neoclassical emphasis on continued growth is worth exploring in the context of the presumption of increased well-being. For example, what is remarkable is how GDP had consistently increased in developed countries, yet measures of happiness and well-being have either fallen or remained flat. Similar to observations by Gordon, GPI (Genuine Progress Indicators) moves in tandem with GDP up to a point, then flattens out or even falls as overall quality of life decreases (Kubiszewski, et al., 2013). It is important to remember that GDP is simply a measure of the value of market-based transactions, whether beneficial to society or not. Equally important, non-GDP transactions include work done at home and volunteer activity, which could continue to constitute growing shares of overall activity.

Another criticism of GDP as a measure of progress posits that once basic needs are met people don't seem to get much happier than they are already. So as opposed to standard measures such as household income, the salient attributes of minimal needs could be a simple and descriptive short list consisting of the five network connections, a room of one's own, proper nutrition, access to healthcare, transportation and education, and some discretionary income - all intended to serve as an enabler of human accomplishment in whatever form. Amartya Sen proffers a freedom-oriented view of sustainability, which include fulfilment of needs, but also the possibility of using reason and freedom to institute valuational change in society (Sen 2013). In short, to live wisely and agreeably and well (Skidelsky and Skidelsky 2012: 154-167).

With a world population estimated to be 9-12 billion before the end of the 21st century, the earth is on track to become a much more crowded place. A planet that full of people will have to be managed very differently. Pressure on limited resources and ecosystem services – exacerbated by growing inequality – will generate greater instability, resulting in political conflict and broad institutional changes (Piketty 2015; Scheidel 2017: 443-444).

Yet once the peak occurs, global population will almost certainly begin to decline, at least gradually by the mid-to-late 21st century (Robbins and Smith 2016). This novel scenario will present its own set of fresh challenges for future economists. Gradual global population decline on its way to some kind of

steady-state may be as difficult to navigate as the more densely populated earth in the decades ahead. A political economy addressing naturally occurring population decreases has not been articulated. Similarly, a departure from growth-only economics has no precedent in industrialized economies.

In the meantime, societies will confront important choices in the years ahead. Jared Diamond outlines two strategies that have prevented ecological and societal collapse in various geographies throughout history. The first is long-term planning, and the second is the willingness to reexamine societal core values (Diamond 2011: 522-525). Both of these items will present non-trivial challenges for developed countries to address.

Long-term planning is not the hallmark of most industrialized societies that often lurch from one election to the next. In the corporate world, the planning horizon is often shorter, from quarter to quarter.

Reexamining core values will not be an easy prospect either. Since the advent of consumer societies - in many ways driven by relentless depletion of ecosystem services - the basic components of what is needed for happiness has been largely lost. Instead, the more likely scenario is that the lifestyle to which the developed world should probably aspire will instead be forced upon it.

Perhaps one day fusion energy, space-based solar power or cost-effective space travel will expand the feasible boundaries of the planetary ecosystem. However for now, available ecosystem services provided by a finite planet with a surface area of 510 million square kilometers are all humans have with which to work. In so many ways, planet earth will continue to get smaller in the years and decades ahead.

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