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Joshua Farley, PhD
Associate Prof, Community Development and Applied Economics
Fellow, Gund Institute for Ecological Economics
205 B Morrill Hall
University of Vermont
Burlington, VT 05405

Skyler Perkins, University of Vermont

Abstract: Building a green economy confronts two critical and conflicting scale issues. To avoid environmental catastrophes, we must dramatically reduce throughput—carbon emissions alone must fall by over 80%. However, modern economies are so dependent on fossil fuels and other forms of throughput that far more modest reductions could result in economic catastrophe. New technologies can help bridge the gap between these two conflicting thresholds, but must be developed and disseminated as rapidly as possible. Current efforts to speed up technological innovation rely on strengthening intellectual property rights. However, scientists competing for property rights are unlikely to share information, slowing the advance of knowledge. Environmental catastrophes threaten public goods and are likely to have the worst impacts on the poor, providing little incentive for market investments in technologies that protect them. Patents on new technologies raise their prices for 20 years, slowing dissemination and preventing other scientists from freely improving the technology. Knowledge is expensive to produce but its value is maximized at a price of zero, and as a result is best produced through cooperation, not competition. Building a green economy requires public investment in open source knowledge, ideally funded by fees on throughput.

Introduction

There is a growing acceptance that we must 'green' our economy, but little consensus about what that entails. The OECD calls for green growth [1], while others believe that a steady state economy or even degrowth is a prerequisite for sustainability. [2-8]. The basic criteria for a green economy however are quite clear. A green economy cannot use renewable resources any faster than they can regenerate. In fact, we must reduce the rate of use of renewable resources to below their regeneration rate in order to rebuild our seriously depleted stocks. We cannot emit waste products into ecosystems faster than they can be absorbed, and we must be particularly carefully when we extract and concentrate toxic elements from the earth's crust, and release novel chemicals into the environment, because ecosystems have not evolved the capacity to absorb them . In fact, we must reduce emissions rates well below current absorption rates in order to reduce the harmful accumulated stocks of greenhouse gases and other dangerous pollutants. We must also ensure that neither resource extraction nor waste emissions threaten the supply of life-sustaining ecosystem services, again requiring a reduction in both. Finally, we cannot use non-renewable resources upon which we depend faster than we develop renewable substitutes. Failure to develop a green economy must ultimately have catastrophic results.

Unfortunately, the path towards a green economy is rocky indeed. Take the relatively straightforward case of achieving climate stability. We know from the IPCC report that failure to reduce greenhouse gas emissions by greater than 80% will lead to continuing accumulation of GHGs in our atmosphere, likely resulting in runaway climate change [9]. From an economic perspective, the marginal costs of GHG emissions are immeasurably high. However, our economy currently depends on fossil fuels for everything from food supply to communication. Conventional modern food systems for example consume over seven calories of fossil hydrocarbons for every calorie of food that winds up on a plate [10, 11]. Reducing fossil fuel consumption by as little as 50% would leave us unable to feed 7 billion people with current technologies and likely lead to global economic collapse. The marginal benefits of GHG emissions are also immeasurably high with current technologies.

The loss of ecosystem services in general presents a similar dilemma. Failure to restore global ecosystems and biodiversity threatens a catastrophic loss in ecosystem services, including many essential to agricultural production. There is often a significant time lag between human activities and ecological degradation, and again between degradation and biodiversity loss [12, 13]. This time lag offers a window of opportunity to restore ecosystem resilience. However, the greatest threats to ecosystem function include nitrogen, phosphorous and greenhouse gas emissions, land conversion, biodiversity loss, freshwater use and chemical pollution [14]. Agriculture is a leading cause of all of these threats [15]. Measured in terms of ecosystem services lost, the marginal costs of agriculture are immeasurably high. However, for the billion people who are currently malnourished, the marginal benefits of agriculture production are immeasurably high as well.

With current technologies, we face an apparently unsolvable dilemma: failure to build a green economy will lead to a global ecosystem collapse which drags the economy down in its wake, while switching to a green economy with current technologies will likely lead to global economic collapse in the short run. The choice is between disaster now and disaster later. Figure 1 depicts this dynamic.

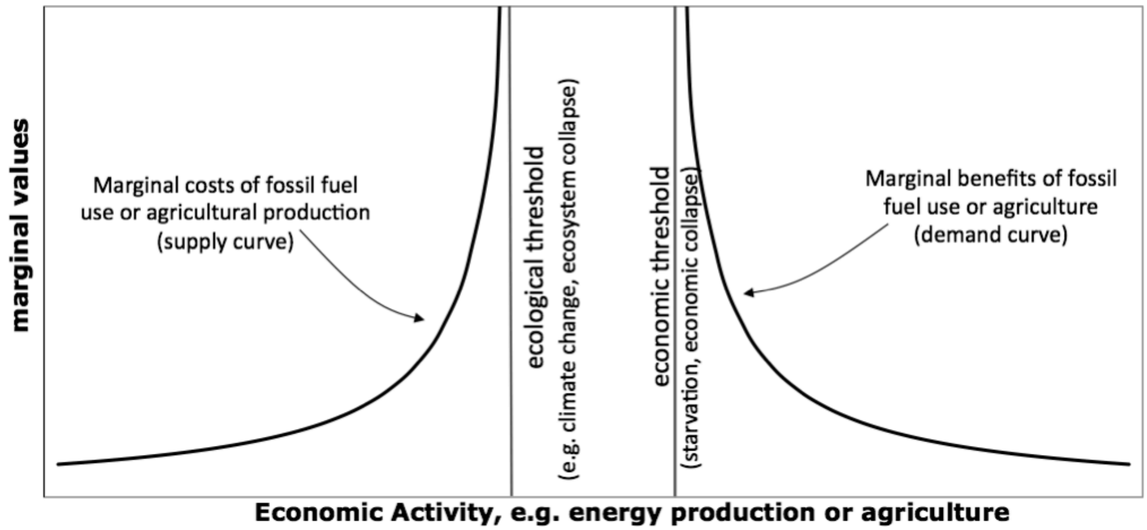

Figure 1. Apparently unsolvable dilemmas: Under current technologies, both the marginal costs and marginal benefits of essential economic activities can become immeasurably high, with the possibility of no 'optimal' solution.

New technologies alone will be unable to solve this problem, but they are almost certainly an essential part of any viable solution. Technology is nothing more than applied scientific knowledge, applied information. For the specific problem of global climate change, we must develop clean alternative energy sources, more energy efficient technologies, better methods for capturing and storing carbon, and so on. Such technologies will reduce the marginal costs of reducing greenhouse gas emissions, shifting the demand curve for fossil fuel emissions to the left, as shown in figure 2. The quicker we can begin the shift, the less radical it needs to be.

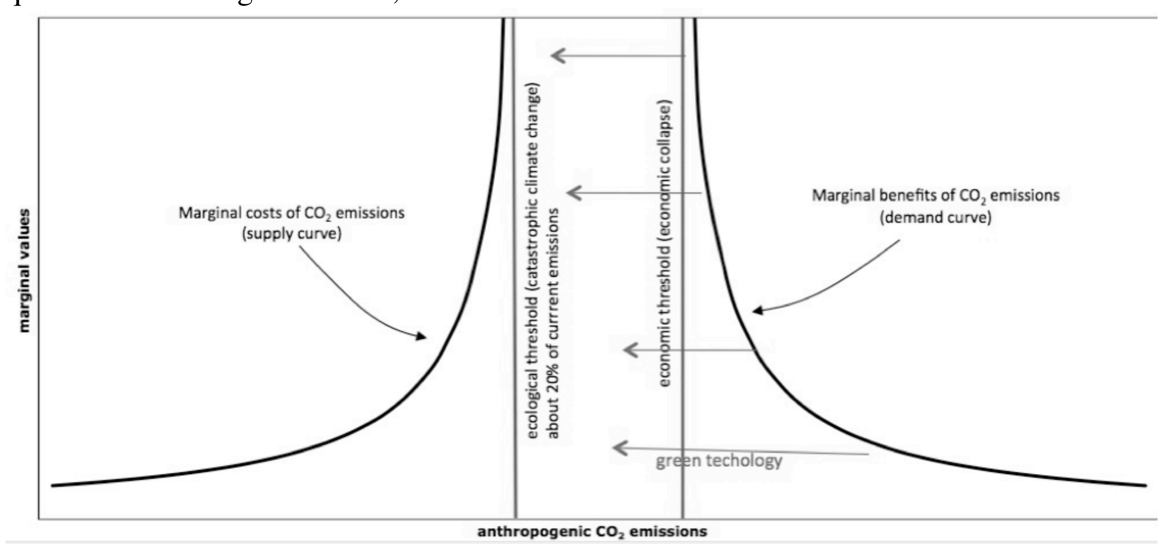

Figure 2. Green technologies can shift the demand curve for fossil fuels to the left

For the specific dilemma of ensuring adequate provision of both food and ecosystem services, we need to develop agricultural systems that replace artificial or non-renewable off-farm inputs (e.g. nitrogen, phosphorus, pesticides, and fossil fuels) and the mining of soil and water with their renewable but dwindling ecosystem service counterparts (e.g. nutrient cycling, erosion control, biological pest controls, water regulation and renewable energy) while simultaneously increasing output [16]. Agriculture practices must help mitigate climate change and adapt to its impacts. Agriculture must not only maintain the natural resource base, but also actively restore critical ecosystem services. To ensure food actually flows to those who need it most, agricultural systems should pay particular attention to the needs and aspirations of poor farmers in marginal environments. The design of green agricultural systems must be based on ecological principles while simultaneously accounting for social and economical capabilities. Such a system would reduce the marginal costs of agriculture, shifting the supply curve to the right: more land could be dedicated to such systems without threatening vital ecosystem services. Increasing food production per unit of agricultural land and restoring degraded lands with agroforestry systems that also produce food would paradoxically reduce the marginal benefits of agricultural land by reducing the threat of starvation posed by restoring farmland to more native-like ecosystems. The transdisciplinary field of agroecology, defined as the "application of ecological science to the study, design and management of sustainable agroecosystems" is built precisely on these principles to achieve these goals (Altieri 2002; Francis et al. 2003). Figure 3 depicts this dynamic.

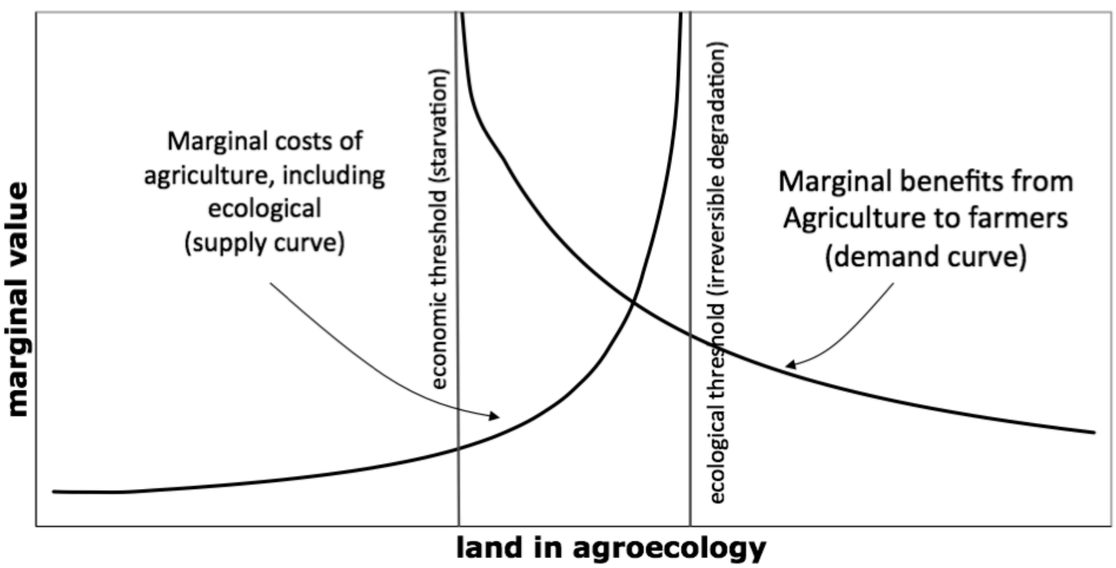

Figure 3: Supply and demand of land in agroecology
By increasing ecosystem services from farmland, agroecology can shift the marginal costs of farming to the right, and by increasing food output on farmlands and native-like it can shift the starvation threshold to the left.

We do not believe that technological advance is sufficient to solve these critical dilemmas, but we do believe it is necessary. Information of course is the basic building block of all technology.

The goal of this chapter is to describe the challenges of producing and disseminating the technologies necessary to create a green economy. As an OECD report states, “If we want to make sure that the progress in living standards we have seen these past fifty years does not grind to a halt, we have to find new ways of producing and consuming things”[1]. We argue that this change is especially important with the production and ‘consumption’ of information. Specific challenges include the promotion of the right type of research and development (R&D), the production of the desired technologies at the lowest possible cost, and maximization of their value once they exist, which for green technologies will rapid and extensive dissemination. As we lay out these challenges, we will explain why markets are ill-suited to overcome them. We then describe a variety of economic institutions that can overcome them, and assess their viability. We conclude with suggestions for steps forward.

Promoting the right type of R&D

Our first challenge is to design economic institutions that promote the right type of technologies for a green economy. This task can be subdivided into a number of sub-challenges.

To begin, appropriate technologies must protect and provide critical ecosystem services upon which we depend for survival. However, many of these ecosystem services, such as climate regulation, disturbance regulation, protection from UV radiations, and regulation of atmospheric gasses, are inherently non-excludable resources, which means that it is impossible to prevent someone from using the resource if it exists. There is no direct market incentive to provide such technologies because, since the benefits they generate cannot be bought or sold. Other resources such as oceanic fisheries or waste absorption capacity of unregulated pollutants could be made excludable if we chose to, but until we choose to do so, there are greater incentives to develop technologies that overuse these resources than ones that protect them [17].

A related problem is that it is difficult and expensive to make information itself excludable. A profit-seeking firm is unlikely to shoulder the costs of developing a new technology if other firms can readily copy it at minimal cost. The traditional solution to this problem is to protect intellectual property rights via patents, but in today’s information age, increasing accessibility to information makes this ever more difficult to achieve. Furthermore, the proliferation of intellectual property rights can actually deter the advance of knowledge by making it more difficult to build on the knowledge of others. This is particularly true for scientists seeking to develop technologies that provide public goods or target the poor, as these do not generate revenue to pay royalties on existing patents [18]. From the perspective of building a green economy, resources spent protecting private property rights to information are simply wasted.

Recent surveys suggest that patents do indeed have a heavy influence on the direction of research. A AAAS survey found 35% of academics in the biosciences reported difficulties in acquiring patented information necessary for their research; of those scientists, 50% had to change the focus of their research, and 28% had to abandon it all together [19]. Another survey found that the majority of scientists interviewed believed that intellectual property rights to research tools had a negative impact on research in their area [20]. As Universities seek ever more patents, they push professors to focus on the production of patentable, market goods. Given a finite supply of scientists, this pressure comes at the expense of producing technologies that provide the public good benefits needed to solve our problems.

Even apart from the costs of enforcing intellectual property rights, appropriate technologies can be very expensive to develop. Costs are often beyond the capacity of a single industry. Information in fact is an ideal example of a natural monopoly, with very high fixed costs of production, and negligible marginal costs. For example, developing a safe, clean alternative to fossil fuels may costs hundreds of billions of dollars, while transmitting that information over the Internet to other potential users is essentially zero. The total cost of providing the information is independent of the number of people using the technology. The more people who use the technology, the lower the average total cost. In other words, the more people who use the knowledge, the lower the total cost per person, as seen in figure 4. Figure 4 also shows the market demand curve for some hypothetical green technology along with the marginal revenue curve. More people will use the technology as the price declines, but marginal revenue falls to zero when the impact of a falling price overwhelms the impact of a growing number of consumers. Lowering prices to increase the number of users as this point also lowers total revenue, hence profits. Since the marginal cost is zero, the private economic surplus is given by the area under the demand curve minus the cost of producing the technology, shaded in green, which is unaffected by the number of consumers. Green technologies of course produce positive externalities or reduce negative externalities. The marginal social benefits of the technology are therefore much higher than the marginal private benefits depicted by the demand curve, but the goal of a private sector firm of course is to maximize profits, so it ignores social benefits. As drawn, there is no price at which the total revenue from the technology, shown by the brown rectangle, will exceed the total cost of producing it, even when the private economic surplus is positive. Competitive markets simply will not produce such technologies.

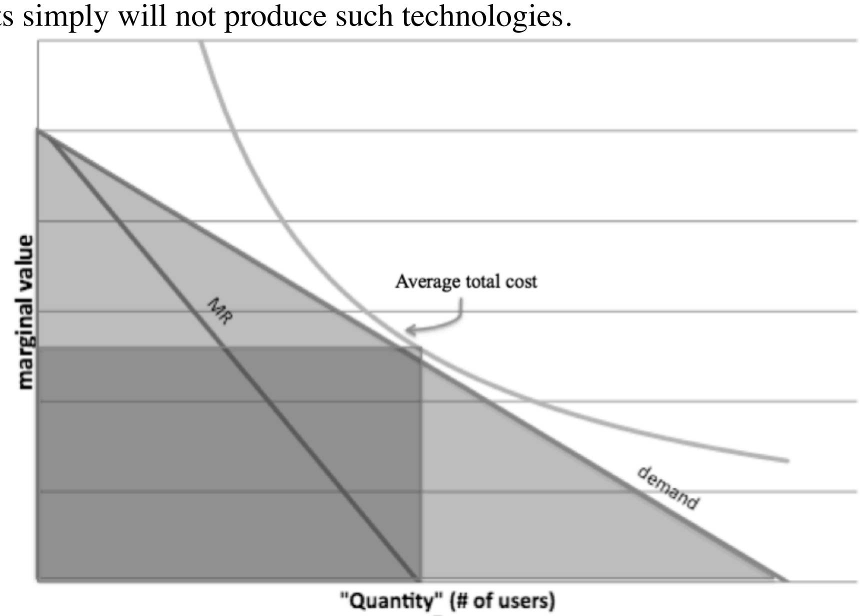

Figure 4: Information as a Natural Monopoly.
As depicted here, the costs of developing a natural monopoly always exceed the total revenue it can generate, even when economic surplus is positive.

These problems no doubt contribute to a serious lack of research and development in technologies required for a green economy. For example, the energy sector is one of the most important for a green economy, but is also one of the least innovative on the planet. Private sector investment in energy technology fell steadily from the 1980s before rebounding slightly in recent years, and accounts for only .03% of sales in the US [21]. It invests only 6% as much in R&D as the manufacturing sector [22].

Finally, technologies must also meet the needs of the poor. The one billion people currently suffering malnutrition are destitute by definition. The worst impacts of global climate change are likely to strike the poorest countries, which ironically are those who made the least contribution to the problem. Market demand is determined by preferences weighted by purchasing power. The purchasing power of the destitute is negligible, so they have no market demand, and market forces will not invest in technologies that target their needs. This is particularly true when scientists must pay royalties on technologies required by their research. For example, when scientists biogenetically modified rice to produce vitamin A, they found that they had infringed upon dozens of patents. While many of the companies holding the patents have agreed to allow poor farmers to eventually the rice, the legal obstacles involved have increased total costs and slowed dissemination of the technology [23, 24].

Producing technologies at the lowest possible cost

The second challenge is to produce the required technologies at the lowest possible cost. The most important input into new technologies, into new information, is existing information. Information has the unique characteristic that it improves through use. Like many people in the open source movement have pointed out, information is like grass that grows longer the more it is grazed. In economic terms, information is non-rival, meaning that use by one person does not leave less for others to use, or even anti-rival, meaning that use by one person leaves more for others by adding improvements. We need institutions that promote the sharing of information during the research process.

There is a widespread though often faith-based belief that markets are effective at minimizing costs of production, but for information this is unlikely to be the case. Markets require property rights, which in the case of information means patents and royalties, and these increase the cost of doing research in several different ways. First, as pointed out above, they force scientists to pay for access to existing information. For example, studies have found that each new medical technology infringes on an average of 50 existing patents [22]. Paying royalties on these patents can dramatically increase the cost of doing research and of using new technologies. It can also slow the development of knowledge [25, 26]. Second, a huge amount of effort goes into creating patents. The US patent bureau alone receives 500,000 patent applications per year, which may run to hundreds of pages with hundreds of claims each. There is an existing backlog of 700,000 claims [27]. Third, the legal costs of enforcing patents can also be quite high for both the patent owner and the court system. Over 1% of patents end up in litigation [28], with cost per case typically running to $2 million dollars or more [29, 30]. Forth, patent trolling is the creation or purchase of patents by firms simply to challenge patents held by other firms. Challenged firms frequently settle out of court simply to avoid litigation costs [31]. Fifth, many firms patent technologies they do not plan to use simply to keep others from using them, further slowing innovation [32].

Finally, the nature of information as a natural monopoly also increases the costs of producing technologies under a competitive market system. In a market economy, firms will compete to be the first to develop a new technology. Each will hire a separate team of scientists with separate laboratories. These teams are unlikely to share information with each other, even though information improves through use, and sharing would likely speed the rate of progress. The result is a duplication of high fixed costs. When one firm wins the race and earns a monopoly, the redundant research of the other firms becomes worthless.

Maximizing the value of existing information

Building a green economy requires the widest possible dissemination of green technologies. This is intuitively obvious, but is also a clear result from economic theory, which tells us that economic surplus is maximized when marginal costs equal marginal benefits. Since the marginal cost of the additional use of information is zero, it should be used until the marginal benefit is also zero, which will only happen at a price of zero. If one views the protection of ecosystem services as a positive externality of green technologies, it might prove optimal to subsidize the use such technologies, rather than restricting access through patents [33].

As previously explained, patents create private property rights in information, allowing it to be bought and sold. The problem with this is that prices ration access—only those willing to pay the price are allowed to use the information.

The inefficiency of using prices to ration access to information is perhaps best illustrated through example. The Convention on Biodiversity awards countries property rights to endemic biodiversity and the genetic information it contains. Historically, countries that find new strains of contagious diseases make them available to the WHO, which allows anyone to develop vaccines or cures for that disease. Typically this means that the genetic information would be passed on to private sector corporations, which would compete to develop a vaccine. As discussed above, such competition is likely to increase the costs of developing the vaccine. Indonesia recently discovered a new strain of avian flu. In terms of allocating a successful vaccine, Indonesia realized that a private corporation would likely price the vaccine at a cost too high for most of the world's poor, including Indonesia's citizens. Indonesia therefore threatened to sell the virus to a single corporation, presumably with the requirement that any resulting vaccine be made available to Indonesia's citizens [34]. Rationing access to the virus would reduce the likelihood of discovering a vaccine, while rationing access to the vaccine would increase the likelihood of a pandemic [35]. Charging for information fails to maximize its value.

Returning to figure 4, imagine that technological breakthroughs have lowered the cost of developing an environmentally friendly technology, shifting average fixed costs down below the market demand curve, as shown in figure 5 below. The firm can now make a profit by creating, patenting and selling the technology. The patent allows the firm to capture monopoly profits, so it will produce where marginal revenue is zero. Total revenue is depicted by the brown rectangle. Total costs, which are constant for any level of use, are depicted by the darker brown rectangle, and profits by the lighter colored rectangle above it. The net market benefits to society are given by the private profits plus the triangle between the profits and the demand curve. However, the green triangle labeled "deadweight loss" depicts the additional *net* market benefits to society if the technology were to be given away free of charge. This is the cost to society caused by patent pricing. Any positive price would cause some deadweight loss, but the lower the price, the less the loss. Of course, if the green technology generates positive externalities, then the value of these externalities is also reduced due to price rationing.

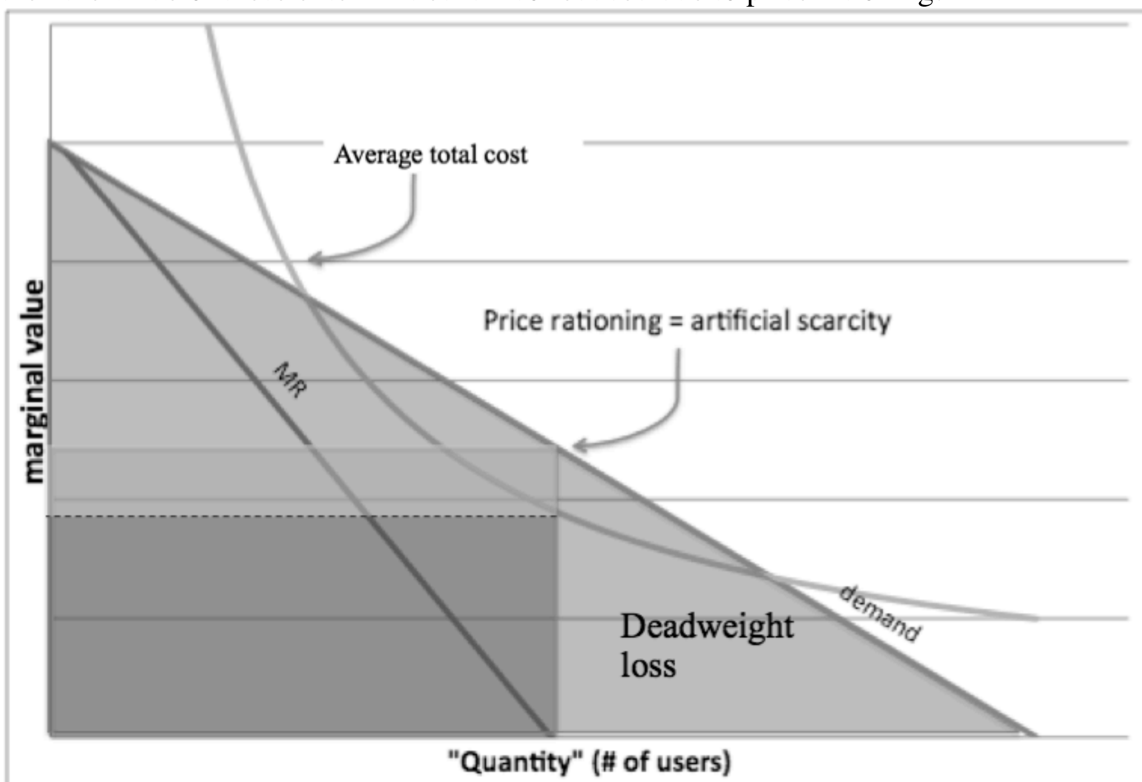

Figure 5: Information as a profitable natural monopoly
Firms will produce less of the new technology than is socially desirable, especially if the technology generates positive externalities.

If the economic profit made from this technology are large enough, they might attract other firms to create a nearly identical product, sufficiently different that it doesn't infringe on the patent—frequently called a 'me too' product [36]. However, this would require new investments in R&D simply to replicate an existing product, thus increasing fixed costs. The more firms that replicate the fixed costs, the greater the total cost to society. Competition under such circumstances can actually drive up the costs. Potentially, another firm will develop a better product, but the likelihood of this happening is far higher if new firms can improve on the existing product instead of producing a new one from scratch.

To maximize the value of existing information, it instead should be freely available to all firms, reflecting its marginal cost of zero. The firms would then compete to produce the new technology as cheaply as possible. Of course, someone must cover the real costs of producing new innovations, and innovators must be rewarded.

The Efficient Provision of Green Information

The market provision of information confronts an irresolvable paradox. The efficient price of information is zero, but at that price, information will provide an inadequate supply of innovative technologies. Patents create an incentive for the market provision of information, but lead to price rationing and inefficiently low levels of consumption. Markets also fail to provide technologies that protect or restore public goods, and fail to meet the needs of the poor. We require alternative economic institutions based on cooperation, not competition. We quickly review two potential solutions: public sector provision and commons-based peer production.

Public Sector Provision

Given the public good characteristics of information, public sector provision seems an obvious solution. This is especially true for the information required for a green economy, for technologies that protect and restore public goods. Public provision is hardly a radical suggestion, as there is a long tradition of government financed research and development in public goods. The US land grant universities are just one example of organized public support for R&D in agriculture, with results freely disseminated as public goods, that dates back over 150 years [37]. Public sector investment in agricultural R&D averages rates of return on the order of 65% [38, 39]. Investments in agroecology are potentially much higher, especially if one accounts for the environmental benefits generated [40, 41]. In spite of the growing need for R&D that protects public goods, however, the share of public funding for research has declined dramatically in recent decades. In the US, federal funding for R&D has fallen from well over 60% for most of the 1960s to well under 30% in recent years, with the private sector making up most of the difference. Federal funding continues to account for the bulk of basic research however, and the bulk of funding for universities [42]. However, since the Bayh-Dole act facilitated the creation of patents on publicly funded research, the number of patents held by universities has skyrocketed [43].

Given globally interconnected ecosystems, green technologies inevitably provide global public goods. Ideally, all countries should therefore jointly invest in the green R&D. Shared investments may be difficult to achieve initially, and one could easily envisage politicians in one country refusing to invest in open source green technologies because other countries would free-ride on their investments. However, the more widely used a green technology, the better off everyone becomes. As other countries use the technologies, they are likely to evolve and improve, benefitting the country that initially invested in their production. Free-riding is virtually impossible.

Unfortunately, it is not clear that governments are effectively allocating R&D resources towards solving society's most pressing problems. As in the private sector, government support of alternative energy R&D has fallen substantially since the 1980s. In the US, the President's Council of Advisors on Science & Technology has recommended an increase in energy R&D funding from $6 billion to $16 billion, though an actual increase of that magnitude seems unlikely given the pressures to reduce the federal deficit [44]. Global climate chaos could have dramatic impacts on quality of life and life expectancy, while advances in health care can at best add a few years to our lives. Nonetheless, well over half of US non-defense R&D is spent on health, while investments in energy and the environment are negligible [45]. Furthermore, the Bayh-

Dole act of 1980 allows private sector businesses to patent publicly funded research, with the potential for seriously restricting its dissemination.

Commons-based peer production

Even prior to public sectors and patents, knowledge thrived. The most important advances in human knowledge such as language, culture and mathematics, were large scale 'projects' created by the successful collaboration of groups of individuals "following a diverse cluster of motivational drives and social signals." [46, p. 2] This is know as commons-based peer production. By its very nature, such research is freely available to all. Commons based peer production tends to be most successful when research equipment is quite cheap (e.g. computers), problems can be broken down into small modules of different sizes, and integration of the modules is relatively easy. The modular nature allows contributers to determine their own level of contribution, and self select for the tasks at which they excel [46].

Despite economists assumptions that humans are perfectly self-interested, we know empirically that individuals freely contribute enormous amounts of time to collaboratively solving problems and generating new technologies. Benkler [47] argues that "instead of direct payment, commons-based production relies on indirect rewards: both extrinsic, enhancing reputation and developing human capital and social networks; and intrinsic, satisfying psychological needs, pleasure, and a sense of social belonging. Instead of exclusive property and contract, peer production uses legal devices like the GPL, social norms, and technological constraints on "antisocial" behavior" (p. 1110). Within this peer production community, monetary returns may actually have negative connotations, and can potentially decrease cooperation [46]. Although some computer programmers report being paid for their contributions [48], there is actually evidence from behavioral economics and psychology that monetary incentives can make people more selfish [49, 50], and 'crowd out' the intrinsic motivations to cooperate which drive much of this research [51, 52]. It thus appears that most contributors participate in order to be part of a gift economy, for the status conferred, or to make the world a better place. However, it does not really matter what the particular motivation is for an individual to participate—different individuals can participate for different reasons [53].

Throughout history, technological advances in stone knapping, agriculture, architecture, government, and others involved a similar approach, as did language, culture, and music. The advantage of this approach is that it does not require any changes in intellectual property rights. The problem is that some of the most important societal problems we currently face, such as alternative energy technologies, may require substantial and expensive investments in basic science, additional investments to apply the research, and a significant learning curve to achieve economies of scale. Public sector investments may be more suitable in this case.

Efficient Dissemination: open access and open source

Once information has been produced, there are different ways to make it accessible to all. The two dominant approaches are known as open source and open access.

Open access refers to information that is freely available for all, but which cannot be modified. In the scientific realm, most open access publications and the research behind them are generated by academics, and paid for with salaries or grants, which may also cover the costs of publication. Publications typically contribute to promotions and higher salaries, but non-monetary compensation such as status and prestige provide considerable incentive. There is also a strong element of reciprocation, or 'gift economies', as scientists know that they will also benefit from the contributions of others. Such payments allow researchers to devote full time to a specific problem. However, many academics jealously guard the data underlying their research at least until publication, which reduces the value of the data to society. Also, at the same time that open access publications are becoming more common, so too are patents on research results.

Open source refers to information that is freely available to all and can be modified by anyone. Open source information is generally produced via commons-based peer production. It can be used as is or modified, as long as it is properly cited. More importantly, it is typically protected by a General Public License (GPL) or copyleft. Though anyone can use and alter the work, all subsequent work is protected by the same license, and can never by patented or placed under conventional copyright [54].

One promising alternative for production and dissemination is a hybrid of the open source and open access approaches. One example is the Alzheimer's Disease Neuroimaging Initiative (ADNI), in which a large consortium of researchers looking for biomarkers for Alzheimer's shares all their data and makes findings public immediately. No one owns the data and no one submits patent applications. Scientists on the project are paid for their research with salaries and grants, primarily from universities or the public sector, and also gain status and other non-monetary benefits. Participants have referred to the results as "unbelievable" and "overwhelming" [55]. There are other open source initiatives in the health sciences focused on diseases of the poor, which provide little opportunity for profit in any case [56, 57]. The advantage of this hybrid approach is that it allows scientists to work full time on problems that serve the public good.

The Need for Global Cooperation

In ecosystems, everything is connected to everything else [58]. This means that no single nation can develop a green economy; it must be a collaborative global effort. However, the central goal of a green economy is sustainability; we need to make sure that future generations are able to meet their basic needs. But people unable to meet their basic needs today will certainly not sacrifice for future generations. They will deplete as many resources and spew as much waste as required to fill their own bellies. A green economy is virtually impossible in the presence of misery and poverty.

The IMF classifies 150 countries as "emerging and developing" [59]. Figure 6 depicts the world's countries in proportion to their net forest loss between 1990-2000, which shows that many of the 'developing' nations are depleting their renewable resource base faster than it can regenerate. Developing nations are frequent exploiters of raw materials in general, and also of commodities produced by the most heavily polluting industries [60]. By the standards of a green economy, these countries are becoming poorer.

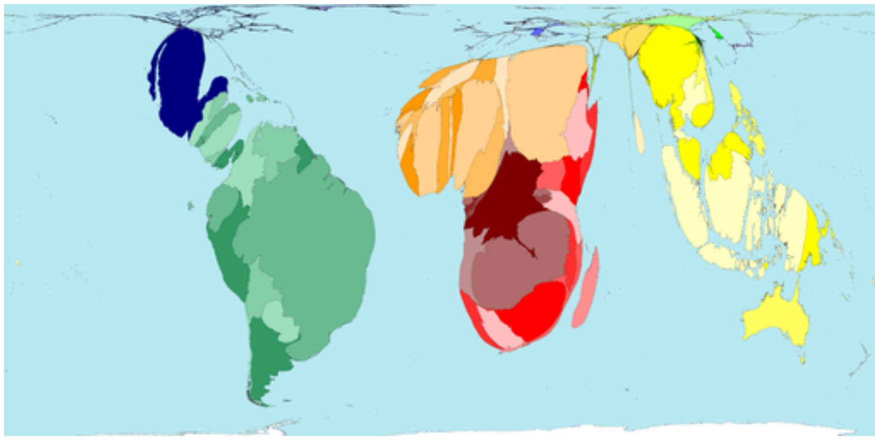

Figure 6. Countries in proportion to their net forest loss1990-2000. *Worldmapper: The World as You've Never Seen It before*. <http://www.worldmapper.org/>. © Copyright SASI Group (University of Sheffield)

To promote poverty reduction, the OECD recommends we focus on "introducing efficient technologies that can reduce costs and increase productivity, while easing environmental pressure" and "alleviating poor health associated with environmental degradation". 1. We heartily concur. However, Figure 7 depicts the world's countries in proportion to the royalties and license fees they receive. It is almost the inverse of the map in figure 6. Rather than providing these countries with the necessary technologies, the OECD countries are enriching themselves by rationing access to technology via the price mechanism.

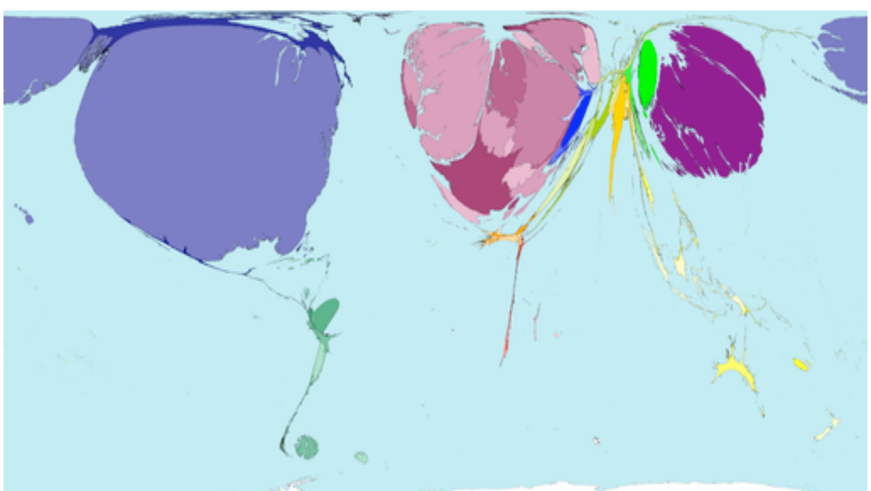

Figure 7. Countries in proportion to royalties and license fees received. *Worldmapper: The World as You've Never Seen It before*. <http://www.worldmapper.org/>. © Copyright SASI Group (University of Sheffield)

Non-ozone depleting compounds offer a clear example of the perversity of this approach. Few people realize that the Montreal Protocol allows less-developed nations to use HCFCs as a substitute for CFCs. Though HCFCs have less impact on the ozone than CFCs, emissions have been doubling every few years, worsening ozone depletion [61]. The Antarctic ozone hole broke records in 2006, and an ozone hole appeared in the arctic in 2011 [62]. Non-ozone depleting substitutes exist, but they are patented, increasing their costs and decreasing their use. Failure to take a cooperative approach to creating and distributing green technologies could prove suicidal.

Funding Green Technology

An important question so far left unanswered is the source of financing for investments in green technology. The obvious answer is that it we capture revenue from anti-green activities, such as waste emissions and resource extraction. Green taxes or cap and auction schemes can be used to charge for resource extraction and waste emissions, sending a price signal that reduces resource depletion and pollution while creating a revenue stream for investment in green technologies. As the OECD says, "creating a global architecture that is conducive to green growth will require enhanced international co-operation. Strengthening arrangements for managing global public goods, especially biodiversity and climate, hold the key to addressing co-ordination and incentive problems." [1] We will ultimately require a broad suite of policy changes to complement green technologies. The wealthy countries have done the most to cause the problems we face and have a moral obligation to start the ball rolling.

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