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The Failure of the Free-Market on a Full Planet*)

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Abstract

Economics is the science of the allocation of scarce resources among alternative ends. Market forces are efficient at allocating market goods: resources that are both excludable (one person can prevent another from using the resource) and rival (one person's use of a good or service precludes use of the same by another), and produce no negative externalities. However, the growth of the human system relative to the global ecosystem that sustains us is rapidly increasing the scarcity of ecosystem goods and services. Many of these services are non-excludable and/or non-rival, and hence not efficiently allocated by market mechanisms. Further, economic 'production' is actually the *transformation* of natural capital, and the process of transformation destroys or degrades the vital ecosystem services that natural capital otherwise provides—i.e. negative externalities are ubiquitous. Neo-classical economists tell us not to worry, that as a good becomes scarce, its price increases and entrepreneurs develop substitutes. Yet non-market ecosystem services have no price, are predominately non-excludable, and will not be produced by market forces. Other economists assure us that we can create markets in environmental goods, or else internalize externalities in the prices of market goods. The former assertion presumably assumes that because we can create markets in waste absorption capacity, which is rival and can be made excludable through proper institutions, we can do so for other environmental services. Such is not the case. The second assertion proposes a task at least as difficult as centralized planning of an entire economy. This paper will show how a proper analysis of ecosystem goods and services in the context of 'rivalness' and excludability can dramatically enhance the rigor of economic analysis and help us develop an economic system compatible with a full planet.

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Introduction

Economics has been defined as the science of the allocation of scarce resources among alternative ends. This means that the three tasks of the economist, in order of importance, are to determine what are the desired ends, what are the scarce resources required to meet those ends, and finally how these resources can best be allocated among those ends. This paper presents the argument that in recent decades, there has been a fundamental shift in the relative scarcity of resources required to meet desirable ends. Specifically, natural capital (goods and service produced by nature) has become more scarce, while the goods and services produced by humans have become less scarce. This change has occurred as we have moved from an empty planet, in which human populations, human production and resource demands were small in comparison to the ecosystems that sustained us, to a full planet, in which human populations and resource demands are very large relative to the sustaining system. Further, we will show that natural capital has fundamentally different physical characteristics that make unregulated markets highly inefficient as an allocation mechanism. This means that efforts to develop a sustainable economy will require non-market institutions.

This paper will first briefly discuss what are the desired ends, and how they can be attained. Next, we examine what resources most constrain our ability to achieve these ends, and show clearly that the most limited resources are six important categories of natural capital. The bulk of the paper will then examine the characteristics of these six categories, and show that none of them are fully amenable to market allocation. What's more, for most of these resources, it is impossible to ever develop effective markets, and efforts to do so will prove fruitless. While we cannot go into great detail over what are the most effective mechanisms for allocating these resources, the conclusion suggests fruitful directions for future research.

The Desirable Ends

The question of what are the desired ends is perhaps the most difficult to answer, at least if we are talking about some kind of ultimate end, some goal towards which humanity should strive. Leaving that question to the philosophers, most people would probably agree that enhancing human well-being for present and future generations is a reasonable intermediate end to strive towards. Of course, this intermediate end is not very helpful unless we know how to enhance human well-being.

Many neoclassical economists, policy makers and politicians seem to believe that the surest (if not the only) path to enhanced well-being is ever greater consumption of market goods, for which our wants are insatiable. It then follows that never ending economic growth is the end towards which we should strive. However, the basis for this belief is tautological. Neoclassical economists claim that the only objective information available concerning human well-being is revealed preferences[3]. If preferences by definition can only be revealed through market transactions, it is not surprising if they subsequently reveal that people prefer more market goods.

In contrast, we believe that human well being is generated by our ability to satisfy a number of different needs, and these needs are finite. While exactly what these needs are is subject to much debate, Chilean economist Manfred Max-Neef (1992) reasonably categorizes them as subsistence, affection, creation, freedom, participation, understanding, protection,

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[3] Throughout this paper, I will refer to the viewpoints of neoclassical economists. This by no means implies that all neoclassical economists share the viewpoints attributed to them, but only that it is the majority viewpoint.

idleness and identity, and stresses that each must be satisfied in terms of having, doing, being and interacting. Different 'satisfiers' allow us to meet different needs, and most satisfiers are not market goods. In fact, we believe that consumption of market goods helps us to satisfy very few of our fundamental human needs. What's more, on a full planet, one in which the human system is very large in relation to the planetary ecosystem that sustains it, we will show that excessive production of market goods actually undermines our ability to satisfy many needs and is therefore destructive of our well-being.

The Scarcest Resources

Having examined the desired ends, we turn to the scarce resources. It follows from the neoclassical economics perspective that scarce resources are market goods (in particular human made market goods) and the resources required to produce them. Because most neoclassical economists believe in unending economic growth, presumably there can never be absolute scarcity of the resources required to produce market goods, only relative scarcity. That is, while some resources may be scarcer than others, technological innovation and market forces ensure that we will never run out of resources all together. As resources are essentially inexhaustible, neoclassical economists pay most attention to only two that are presumably in the shortest supply: labor and human made capital.

Once again, our position is quite different from the mainstream. As there are many types of needs, there are many ways to satisfy them. However, satisfaction of any human need (especially via material consumption) ultimately depends on the finite (i.e. absolutely scarce) quantity of low entropy matter energy supplied by the planetary ecosystem that sustains us. We refer to this as natural capital. All economic production is merely the transformation of this natural capital into forms that (ideally) satisfy human needs. Labor and capital are agents of transformation, i.e. efficient causes, while natural capital provides the material that is transformed, i.e. material cause. It is not immediately obvious that needs such as identity, freedom and affection require much matter-energy, but they obviously require humans, and humans require matter-energy to sustain themselves. It is true however that satisfying many human needs requires few resources beyond what is required for survival. Thus, we distinguish between economic growth, which is increasing flows of low-entropy matter energy through the economic system and back to the ecosystem as waste, and economic development, which is increasing ability to satisfy human needs. If resource intensive consumption of market goods is the most effective way to enhance well-being, then the potential for economic development is particularly limited.

Moreover, in addition to supplying the raw materials for all economic production, natural capital also directly provides services that facilitate the economic transformation process and enhance human well-being. These include life support services without which humans could probably not even survive, such as local, regional and global climate regulation, protection from ultraviolet radiation, nutrient cycling, waste absorption, water purification and numerous others. Natural capital also creates the conditions necessary for its own reproduction. How does natural capital provide these services? The raw materials provided by natural capital are components of ecosystem structure— that is, they are the mineral resources, organic matter, and individuals and communities of plants and animals of which an ecosystem is composed. When all the structural elements of an ecosystem are in place, they create a whole that is greater than the sum of the parts, and generate ecosystem functions as emergent phenomena from the complexity of ecosystem structure. An ecosystem function that has value to human beings is called an ecosystem service. As all market goods must be produced from the structural elements of natural capital, and depletion of structure diminishes function, production of market goods in general must reduce the ability of the ecosystem to generate ecosystem services (Farley, 1999).

For most of human existence, natural capital was not very scarce relative to human needs, and hence was not very important to economic analysis. Raw materials were often locally scarce, but were not globally scarce. Relative to the human population and scale of the human economy, the global supply of raw materials seemed infinite. An abundance of healthy ecosystems meant an abundance of ecosystem services. The scarce factors were labor and capital, the agents of transformation. The planet was relatively empty. Today however, human beings directly or indirectly appropriate close to 40% of net primary productivity (Vitousek et. al., 1986). In many cases, damage to ecosystem services through over extraction of ecosystem structure and waste emissions has led to a decrease in raw material production by natural capital. At the same time, per capita economic production of market goods has increased enormously in the past few centuries. Human impacts on the sustaining system are enormous. The planet is now full. This transition from a relatively empty to a relatively full planet has changed the relative scarcity of resources. Formerly, human made goods and services were scarce, and ecosystem goods and services were super abundant. Now, the opposite is true, independent of whether we believe increased material consumption or the satisfaction of a broader array of human needs are the appropriate ends we should strive towards. The question we ask is what impact has this change in relative scarcity had on the appropriate means for allocating resources?

The Suitability Of The Market For Allocating Natural Capital

Neoclassical economics argues that the market is the most effective mechanism for allocating the vast majority of scarce resources. Most economists believe that where markets do not exist, they should be created. We are the first to admit that markets are superb at efficiently allocating a certain class of goods, and this class of goods includes the human made products that were indeed very scarce when neoclassical economic theory was initially under development. This does not in any way mean however that markets are therefore efficient at allocating all resources, and we will spend the remainder of this paper showing why markets will not lead to the efficient allocation of the types of goods and services that have now become the scarcest. We will also show why underlying physical properties of goods and service supplied by intact ecosystems means that it in most cases, we cannot create markets to effectively allocate them. Attempting to create markets for all goods is a fruitless and potentially destructive endeavor. We argue instead that new institutions for allocating our scarcest resources must emerge alongside markets.

Before we attempt to justify these statements, we must first point out that what we are proposing here is not revolutionary, but evolutionary, and simply another phase in a long evolutionary process. For most of human existence, we were nomadic hunter-gatherers living at low population densities as small bands. When resources became locally scarce, we moved on to where they were more abundant. Mobility was essential to survival, and accumulation of private property reduced our mobility (Sahlins, 1972). With the advent of agriculture and population growth, land became a scarce resource, and property rights to land became essential. The industrial revolution created dependence on non-renewable resources. While such resources became scarce and acquired prices, they were still less scarce than the machines and labor required to extract them. Non-renewable resources have grown scarcer, but perhaps more important is their impact on renewable resources. Fossil fuels have allowed us to extract renewable resources at an ever-increasing pace, and non-renewables in general have generated enormous flows of novel wastes, which threaten global ecosystem services. As a consequence, ecosystem goods and services are rapidly becoming the scarcest resources, if they are not already (Daly, 1994). If we are able to create an effective system for allocating ecosystem services, then undoubtedly continued evolution of the economic system will create new scarce resources in the future.

We now turn to the issue of market allocation of ecosystem goods and services to achieve either continued growth in material consumption or an increased capacity to meet the full suite of human needs. In either case, natural capital is the scarcest resource.

Market failures

Excludability and Rivalness

Given the importance of markets both in theory and real life, our first task is to assess the capacity of markets to allocate natural capital. For markets to efficiently allocate a resource, the resource must be both excludable and rival. An excludable good is one for which exclusive ownership is possible. That is, a person or community must be able to use the good or service in question, and prevent others from using it if so desired. Excludability is virtually synonymous with property rights. If a good or service is not excludable, then it will not be efficiently allocated or produced by market forces. The reason for this is obvious. Market production and allocation is driven by profits. If a good is not excludable, someone can use it whether or not any producer of the good allows it. If someone can use a good regardless of whether or not they pay for it, they are considerably less likely to pay for it. If people are unwilling to pay for a good, there will be no profit in its production, and it will not be produced by market forces, or at least not to the extent that the marginal benefit to society of producing another unit is equal to the marginal cost of production.

Excludability can be determined by institutions and/or by the physical characteristics of a particular good or service. In the absence of institutions that protect ownership no good is truly excludable unless the possessor of that good has the physical ability to prevent others from using it. Some type of institution, be it government, religion or custom, is required to make any good excludable for someone who lacks the resources to defend her property. It is fairly easy to create institutions that provide exclusive property rights to tangible goods such as food, clothing, cars and homes. Slightly more complex institutions are required to create exclusive property rights to intangibles such as information. Patent laws protecting intellectual property rights are ubiquitous in modern society, but it remains difficult to enforce such property rights. For many services, such as most of those produced by ecosystems, it is virtually impossible to design institutions that would make them excludable. We cannot even conceive of a workable institution that could give someone exclusive ownership of the benefits of the ozone layer, climate regulation, water regulation, pollination, or a host of other ecosystem services. It is often possible to establish exclusive property rights to ecosystem structure (e.g. trees in a forest) while at the same time impossible to establish such rights to the services that structure provides (e.g. regional climate regulation). When there is no institutional regime enforcing excludable property rights to a good or service, that good or service is non-excludable.

We define a rival good or service as one for which 'use of a unit by one person prohibits use of the same unit at the same time by another.' Rivalness may be qualitative, quantitative or spatial in nature. A non-rival good or service therefore is one where use by one person has an insignificant impact on the quality and quantity of the good or service available for another person to use. Rivalness is an inherent property of the good or service in question, unrelated to prevailing institutions. Climate stability, the ozone layer, beautiful views and sunny days are a few of the non-rival goods produced by nature. Information, streetlights and national defense are some made by humans. Market efficiency requires that the marginal cost to society of producing or using an additional good or service be precisely equal to the marginal benefit. However, if a good is non-rival, an additional person using the good imposes no additional cost on society. If markets allocate the good, it will be sold for a price. If someone has to pay a price to use a good, he or she will only use the good until the marginal benefit is equal to the price. The price is greater than zero, while the marginal cost of additional use is zero. Therefore, markets will not lead to efficient allocation of non-rival goods, or conversely, a good must be rival to be efficiently allocated by the market.

There are actually two types of non-rival goods and services. Some non-rival services, such as UV protection by the ozone layer, are not affected by the number of people using them. For other non-rival goods, use by too many people can seriously diminish the quality of the good or service. For example, if I drive my car down an empty road, it does not diminish your ability to drive down that same road. However, if thousands of people choose to drive down the same road at the same time, it results in traffic jams, and the ability of the road to move us from point A to point B is seriously diminished. Such goods are non-rival but congestible, and for shorthand will simply be referred to as 'congestible'. Note that congestibility is an issue of scale—as scale increases, some non-rival goods can acquire attributes of rival goods.

What happens when goods and services are non-rival, non-excludable or both? The simple answer is that market forces will not provide them and/or will not efficiently allocate them. However, we need to be far more precise than this if we are to derive policies and institutions that will lead to the efficient allocation and production of non-rival and/or non-excludable resources. Effective policies must be tailored to the specific combination of excludability, rivalness and congestibility that characterize a particular good or service. The possible combinations are laid out in Table 4-1, and described in some detail below.

	Excludable	Non-excludable
Rival	Market goods Food, clothes, cars, houses	open access resource (tragedy of the commons) e.g. ocean fisheries, logging of unprotected forests, air pollution from unregulated sources.
Non-rival	Potential market good, but if so, people consume less than they should. e.g. information and technology	pure public good e.g. streetlights, national defense, most ecosystem services
Non-rival but Congestible	Market goods, but greatest efficiency would occur if price fluctuates according to usage. e.g. toll roads, ski resorts	Non-market good, but charging prices during high use periods could increase efficiency. e.g. non-toll roads, public beaches, national parks

Table 4-1: Market relevance of excludability, rivalness and congestibility. (Adapted from Farnsworth et. al., 1983)

Open Access Resources

The first class of goods and services we will examine are open access resources—those that are non-excludable but rival[4]. Use of such goods commonly leads to what Garret Hardin

[4] It is important to point out that 'open access' is not an inherent property of a good, but rather is due to the type of institutional regime that exists. Thus, it is probably better to refer to 'open access regimes'(Bromley, 1993).

(1968) has called 'the tragedy of the commons.' The classic example Hardin used was the grazing commons once common in England. If everyone shares grazing land, one person adding an additional cow means all cows get less grass. The disadvantage of thinner cows is shared with everyone, while the individual gets all the benefits of the added cow. If everyone thinks in the same manner, households will keep adding cattle to the commons until it becomes overgrazed and the productive capacity declines dramatically. Each person acting in what appears to be rational self-interest destroys the commons, and everyone is worse off than if they had stuck with one cow per person[5]. There are many goods characterized by the tragedy of the commons. Hardin originally wrote his classic article to describe the problem of population growth. Another resource plagued by the tragedy of the commons is oceanic commercial fish species, of which an estimated 69% are over exploited (FAO. 2000) Under open access regimes rational self-interest does not create an invisible hand that brings about the greatest good for the greatest number, but rather creates an invisible foot that kicks the common good in the rear!

Many economists have correctly pointed out that this problem of the tragedy of the commons results from a lack of property rights. If the English commons in the first example had been divided up into 100 equally productive private lots, than the rational individual would graze only one cow in each lot, and the tragedy would be avoided. Unfortunately, for many of the resources of concern to us, the ability to bestow individual property rights is more the exception than the rule, and in other cases we will describe later, property rights will not lead to efficient outcomes. It is also important to recognize that property rights held in common can effectively manage these resources under the appropriate institutions. Nonetheless, sloppy analysis and a lack of rigor on the part of too many economists have led to a widespread belief that establishing individual property rights is the answer to most, if not all, of our environmental problems (Cowen, 1992). It would be exceedingly difficult to establish individual property rights to nomadic animal populations such as oceanic fish, and as we will explain below, impossible to do so for most ecosystem services.

Excludable and non-rival goods

A second class of goods of great interest is those that are excludable but non-rival and non-congestible. The prime example of this type of good is information. In the not too distant past, most information was relatively non-excludable as well as being non-rival. In Adam Smith's time, firms would jealously guard their trade secrets, but if such secrets got out, there was nothing to prevent others from using them. As Adam Smith pointed out, trades secrets were equivalent to monopolies, and "the monopolists by keeping the market constantly understocked, by never fully supplying the effectual demand, sell their commodities much above the natural price… The price of monopoly is upon every occasion the highest which can be got." (p. 164) …"Monopoly, besides, is a great enemy to good management..." (p. 251). In more recent times of course, trade secrets have been protected by patents, an institution which makes them legally

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However, we are discussing here excludability, which is the result of both the existing regime and physical characteristics of a specific resource, and rivalness, which is unrelated to the existing regime. Thus, we use 'resource' instead of 'regime' throughout this discussion.

[5] It is worth noting that what Garret Hardin actually describes is not typical of most common property regimes. Many cultures have owned resources in common, and established effective institutions that prevent the type of behavior described here. This was probably true to some extent of common grazing land in England. Colonialism, ineffective government and market integration have disrupted the institutions that formerly managed common resources (Bromley 1993; Ostrom, 1990). As Bromley (1993) has pointed out, the disruptions to these institutions is the real tragedy of the commons. A better term for the behavior Hardin describes would be the tragedy of open access regimes (Bromley, 1993)

excludable, and hence marketable. The justification for this is the assumption that without excludable property rights, people would not profit from inventing new things. There will therefore be no incentive to invent, and the rate of advance of technology will slow, to the detriment of society.

The problem is that one person's use of information not only has no negative impact on someone else's use, it can actually lead to improvements in quality. Linux provides a case in point. For those of you who are unfamiliar with Linux, it is an open source operating system for computers invented by Linus Torvald. Open source means that not only is the program free for anyone who wants to use it, but the computer codes for this system are available for anyone to use and modify. Computer experts around the world have worked on this operating system free of charge, and as a result it is one of the most reliable systems available (Vaughan-Nichols, 1999). Microsoft in contrast spends enormous amounts of money improving its Windows operating system, which still crashes with frustrating regularity. As of June, 2000, Linux shows the most rapid rate of increase in use of any operating system (Wheeler, no date). Certainly this proves that profits are not always required to spur innovation.

What does this have to do with the allocation of natural capital? Imagine that some corporation develops a cheap and efficient way to harness solar energy and convert it to hydrogen for use in a cheap and efficient fuel cell that they also invent. Both inventions are patented. These inventions could virtually eliminate our dependence on fossil fuels, dramatically reduce the risk of global warming and provide benefits for all mankind. The corporation knows the value of its inventions, and sells the products for an extremely high price. The richer nations can afford the products, and dramatically reduce their CO_2 emissions. Unfortunately, at this price, many third world countries are unable to afford the technology. Luckily for them, they still have massive supplies of coal and use this to fuel their economies instead of the new technology. The billion inhabitants of the industrialized world could send their CO_2 emissions to zero, but if the 5 billion members of the developing world dramatically increase theirs during the time the patent is valid, we end up with unnecessarily severe global warming, and everyone suffers. We have seen similar problems with patents on medicines for highly contagious diseases such as AIDS, or on lack of investments in contagious diseases that primarily affect the poor, such as tuberculosis and malaria (Garret, 2000). The irony is that patent rights are protected in the name of the free market, yet patents simply create a type of monopoly, the antithesis of a free market.

While there may be a solid rationale for allowing patents, there also exist compelling arguments against them. If information is free, it will presumably be used until the marginal benefits of use are just equal to the marginal costs of additional use, which is zero. This is a prerequisite for efficient allocation. On the other hand, if a good is non-excludable, the market provides no incentive to invest in it. Patent laws implicitly recognize this problem by imposing artificial excludability on information, at least for the time period of the patent. Nonetheless, Linux and many other examples show that patents are not necessary to spur invention, so the belief that patents will result in a faster rate of technological advance is nothing more than an assertion.

Non-rival but Congestible Goods

Congestible goods are non-rival at low levels of use and rival at high levels of use. Numerous examples exist, including recreational resources such as beaches, swimming pools, parks and wilderness hiking trails. When goods or resources have these properties, positive prices may produce efficient outcomes for high levels of use, while at low levels of use pricing will lead to inefficient outcomes. This suggests that under certain circumstances, it may be reasonable to treat congestible goods as market goods during peak usage, and non-market goods at other times. Multiple tier pricing structures can be expensive to implement, and whether the strategy is reasonable generally depends on the specific case. Whether the strategy is possible depends on excludability.

Pure Public Goods

As even neo-classical economists readily admit, the market is not capable of optimally producing nor efficiently allocating pure public goods. Theoretically, in a market setting each person is able to purchase a good or service until the marginal benefit from purchasing one more unit of that good or service is just equal to the marginal cost. As long as anyone is willing to pay more for a good than it costs to produce that good, the supplier will supply an additional unit. If a public good exists, however, anyone can use it regardless of who pays for it. An additional unit of a market good is worth producing only as long as at least one individual alone is willing to pay at least the cost of producing another. In contrast, a public good is worth producing as long as all individuals together are willing to pay the cost of producing another unit.

What happens when natural capital can produce either market goods or public goods, but not both simultaneously? Take the example of a small sharecropper in southern Brazil kicked off his land share so that the landowner can grow soybeans under a heavily mechanized system requiring little labor. The soybeans are exported to Europe as cattle feed for higher profits than the landowner could make using sharecroppers to produce rice and beans for the local market. The sharecropper heads to the Amazon and colonizes a piece of land. Researchers have estimated the value of the ecosystem services sustainably produced by this land at roughly \$1660/hectare/year (calculated by the author from Costanza et. al., 1997)[6]. These ecosystem services are primarily public goods. If the colonist deforests the land, he may make a few hundred in profit per hectare for the timber (the timber is of course worth much more on the market, but the market is far away, and middlemen and transportation costs eat up the profits) and an estimated \$33 annualized net profits per year from slash and burn farming (Almeida and Uhl, 1995). In terms of society, there is no doubt that the annual flow of \$1660/year far outweighs the private returns to the farmer. However, the ecosystem services are public goods that the farmer must share with the entire world, and there is no realistic way of giving the farmer or anyone else meaningful private property rights to the ecosystem services his forests supply[7]. In contrast, the returns to timber and agriculture are market goods that the farmer keeps entirely for himself, and existing institutions give him the right to do as he pleases with his private property. Clearly both the farmer and society could be better off if the beneficiaries of the public goods paid the farmer to preserve them. As long as the farmer receives more than a few hundred dollars per year he is better off, and as long as global society pays less than \$1660/ha/year, it is better off. Unfortunately there are a number of serious obstacles preventing this exchange from happening, of which we will mention three. First, most people are ignorant of the value of ecosystem services. Second, the free rider effect means that many beneficiaries of public goods will pay little or nothing for their provision. Third, we currently lack institutions suitable for transferring resources from the beneficiaries of ecosystem services to the farmer who

[6] The forest also produces a number of goods, such as timber and marketable non-timber forest products. These products are valued in the cited paper, but those values are not included in this estimate.

[7] This does not mean that we cannot develop mechanisms for compensating the farmer for providing ecosystem services, it simply means that if the farmer provides them, they are provided for one and all.

suffers the opportunity cost of not deforesting. Thus, from the farmer's point of view, in a market economy deforestation is clearly the rational choice, and society suffers as a result.

Neo-classical economics recognizes the problem of public goods, but fails to adequately address it for three major reasons. First, many economists and policy makers use the terms open access resources and public goods carelessly and even interchangeably, perhaps in confusion over their precise meaning (Randall, 1993). Second, many fail to recognize that for many public goods, including most of those supplied by healthy ecosystems, it is impossible to integrate them into the market system by establishing individual property rights (Cowen, 1992). As a result, a very common 'solution' to the public good problem proposed by economists is to create private property rights to everything. Admittedly, this would work in theory for many open access resources, but it in no way addresses the problem of efficient allocation of non-rival goods. It is also impossible for resources that are by nature non-excludable, regardless of institutions. The third reason for largely ignoring public goods is that many people recognize their existence and the difficulties they pose, but believe that public goods are unimportant relative to market goods, and thus can safely be ignored. Yet if we are correct in asserting that global ecosystems create life-sustaining ecosystem services, then they are indeed at least some public goods are critically important.

Public goods, scarcity, substitution and information

The fact that the global economy is increasingly market driven, and markets do not supply public goods has led to a growing scarcity, both relative and absolute, of public goods in general, and of ecosystem services in particular. There are a number of reasons why this is so.

First, as we noted above, production of market goods requires raw materials and generates waste. Raw materials are taken from ecosystem structure, and therefore reduce the ability of the ecosystem to generate services. Waste returned to ecosystems further depletes these services. In the absence of institutions to control it, market production will systematically undermine the production of absolutely invaluable public goods—the life sustaining functions of our planet.

Many economists claim that there is no particular cause for concern over the depletion of natural capital and the services it provides under the assumption that human made capital is essentially a perfect substitute for natural capital. The argument is that as a resource grows scarce, the price increases, encouraging the invention and innovation of substitutes. One can certainly find numerous examples where the profit motive has apparently produced substitutes for scarce resources, but it nonetheless seems to be an article of faith alone that it will continue to happen into the indefinite future. While it may seem foolish to base such important decisions as those regarding resource exhaustion on inductive reasoning at a time when we are facing tremendous rates of change in human society and the environment that sustains us, for the sake of argument let's accept the technical possibility of infinite substitution. Unfortunately, even if the profit motive does provide such a marvelous spur to our creative processes, what happens when the resources becoming increasingly scarce are public goods in the form of ecosystem services? Such services have no price, and there will therefore be no price signal telling our entrepreneurs that we need substitutes, nor is there any profit to be made by creating such substitutes. The fact is, in a market economy there is no incentive to create substitutes for public goods. Even if incentives did exist, it may prove impossible to substitute for ecosystem services on a large scale.

In general, if new inventions are driven primarily by the pursuit of profits, then we have a serious bias against the invention of public goods or technologies that preserve or restore public goods. Non-market institutions could potentially sponsor research into public good technologies, but even then competition with market forces would undermine their ability to do so. There is a limited pool of resources (e.g. money, scientists, laboratories) for conducting research, and if it is being used in one task, it is simply not available to do another.

As we pointed out above, yet another reason that economists and politicians pay little attention to public goods such as life support functions of ecosystems is that they are unaware of their importance, or even existence. Most of what people see or hear in a day comes from commercial media (Durning, 1992), which is again driven by the profit motive. Media is sponsored by advertising, and the dominant purpose of advertising is to sell products. It follows that little effort is made to advertise public goods, and therefore people are less likely to learn of their importance. Even when people do know the value of ecosystem services, the $654 billion in annual expenditures on advertising will influence people's preferences to demand commercial goods over public ones.

Thus, there is every reason to believe that in a market dominated society, public goods will grow more scarce over time relative to market goods.

Spatial characteristics of public goods

Another complication arises with some public goods produced by ecosystem function that is highly relevant to policy choices. Ecosystems can provide different public good services for different populations. For example, water regulation and storm surge protection provided by intact mangrove forests are local public goods, the role of mangrove forests as a fishery nursery is a regional public good, and global climate stability promoted by the forest carbon storage is a global public good. The provision of these public good services is incompatible with the marketable uses of mangroves, which range from harvesting of firewood to conversion to shrimp aquaculture. Local communities may show little concern for providing national public goods. Sovereign nations may show little concern for providing global public goods. Thus, decision makers at different levels (individual, local, national, international, intergenerational) will have different incentives for preserving or destroying ecosystem function, and these incentives must be understood in order to develop effective policies that meet differing needs at all levels. Unfortunately, political systems are largely based on the nation-state or smaller political units, and hence are inadequate for addressing global issues (Farley, 1999). The inadequacy of existing political and economic systems for managing public goods is particularly problematic in life support services provided by many ecosystems.

Externalities

Another familiar market failure highly relevant to the allocation of natural capital is the externality. An externality occurs when "an activity by one agent causes a loss (gain) of welfare to another agent" and "the loss (gain) of welfare is uncompensated" (Pearce Turner, 1990). Both air and water are great conveyors of externalities. The classic example of a negative externality is a coal fired utility plant that moves in next door to a laundry service that air-dries its wash. The soot from the coal plant dirties the laundry, and the laundry service receives no compensation from the coal utility. If a farmer allows his cattle to defecate in a stream flowing through his property, all those downstream from him suffer the negative externality of polluted water. Alternatively, a farmer might reforest his riparian zone, reducing access by cattle. The canopy shades the stream, killing in-stream vegetation. Water can now run faster, allowing it to scour sediments out of buried springs in the stream, thereby increasing water flow. Shaded water is cooler, reducing the ability of some harmful bacteria to thrive, hence increasing water quality. Downstream landowners benefit from these positive externalities (Farley, 2000).

Because the agent conducting the activity in question is uncompensated for positive externalities and pays no compensation for negative ones, she does not account for these costs or benefits in her decision to pursue the activity. This means that the agent will not conduct the activity until marginal social benefits are just equal to marginal social costs, and the result will be inefficient. If the agents were to be appropriately compensated, then there would be no more externality (by definition), and the activity would be carried out until marginal benefits were equal to marginal costs.

As in the case of public goods, economists have suggested that assigning property rights will eliminate the externality problem. If the laundry has the right to clean air, then the coal utility will be forced to pay the laundry service for dirtying its laundry[8]. Once compensation is paid, the externality is gone. Alternatively, it would be possible to assign the right to pollute to the coal utility. In this case, the laundry would have to pay the coal utility not to pollute[9]. As Ronald Coase (1960) showed in perhaps the most widely cited article ever written on externalities, under certain circumstances regardless of who is assigned the initial property rights, the result would be the same amount of pollution. The implication is that the externality issue requires no government intervention—market forces are perfectly capable of sorting it out.

Serious problems with this analysis include the assumptions of known damage functions and an absence of wealth effects and transaction costs. Damage functions may be easy to assess for market goods such as laundry and electricity, but most externalities affect non-market goods with uncertain values. Wealth effects occur if affected individuals are too poor to pay a polluter to decrease pollution, and must continue to suffer if the polluter is assigned the right to pollute. This is particularly important, as many polluting industries are located in poorer neighborhoods and countries. Transaction costs are simply the costs of thrashing out an agreement. This may not be that difficult in the case of one laundry service and one utility. However, pollution from a coal fired utility affects many people in many locations and even in different countries, and pollution of a river affects all who live downstream. Bringing all of the relevant agents together to the negotiating table would range from difficult to impossible, and even if it could be achieved free riding would become a problem. For example, if I live on the stream polluted by upstream farmers and my neighbors agree to pay the farmers some sum to reduce pollution, I may prefer that level of reduction for free to even more reduction at a positive cost to myself. In fact, as Bromley (1993) has pointed out, if transaction costs were zero, the relevant agents would immediately resolve the problem, and no externality would exist. Coase himself explicitly recognized that high transaction costs could justify government intervention, though this caveat seems to have been lost on many of his devoted followers.

In reality, transaction costs are likely to be very important any time an externality impacts more than a very few agents, which is the general rule rather than the exception. Yet again we must stress that all economic production requires raw material inputs and generates waste outputs, thus depleting ecosystem services. All economic production inevitably generates 'externalities'. Indeed, 'externalities' is a completely inappropriate word, since there is an unbreakable link between economic production, resource depletion and waste emissions. Hence,

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[8] In reality, this will not necessarily lead to an efficient solution in a dynamic setting. For example, if the payment makes the laundry service profitable, another laundry may locate nearby, which would also be profitable with a subsidy from the utility. For fairly obvious reasons, it is inefficient if the promise of a subsidy from the utility attracts businesses that are otherwise harmed by the utility's presence.

[9] In this case, we would have to look at installation of pollution reduction equipment as generating a positive externality for which the laundry service must compensate the public utility.

‘externalities’ are actually 100% *internal* to the economic process. To complicate matters, ecosystem services are public goods characterized by extreme spatial and temporal complexity. As pointed out in our discussion of public goods, not only does everyone in the world benefit from the life support functions of intact ecosystems currently threatened by continued economic growth, but different people benefit to different degrees from different subsets of ecosystem services provided by a given ecosystem. If we further recognize that many of these externalities affect future generations, we must accept that transaction costs generally range from very large to infinite, and the market will not solve the ‘externality’ problem unaided.

Risk, Uncertainty and Ignorance

Further obstacles to market efficiency are uncertainty and ignorance. Uncertainty occurs when we know the possible outcomes of a given action, but not their probabilities. Ignorance occurs when we do not even know the possible outcomes. Under either circumstance, it will of course be only coincidental if we actually reach a point where marginal costs of a given activity are equal to its marginal benefits. For market goods, this is not too serious an obstacle. In general, properties of market goods are fairly well known, information is widely available, and the market determines their value. For ecosystems and the services they generate, however, it is a far different matter. We really know very little about ecosystem services and to what extent they will be affected by human activities. The costs of acquiring additional information can be extremely high, but so can the costs of not acquiring that information, and we generally have little basis for judging whether the costs of acquiring additional information are justified by the added benefits. To make matters worse, in the case of decisions affecting ecosystem services, the costs of ignorance are likely to be born by the public, and often by future generations, while the costs of acquiring knowledge are generally born by the individual decision-maker. As highly complex emergent phenomena, ecosystems and the services they provide are characterized by significant discontinuities and unpredictable behavior. This means that no matter how much effort we invest in acquiring new information, we are still likely to be surprised by unexpected and perhaps catastrophic outcomes. To complicate matters even further, the impact of my actions on ecosystem services is highly dependent on what others choose to do, adding another layer of uncertainty to my decisions. In contrast the utility I derive from purchasing a market good is in most cases fairly independent of what anyone else chooses to do.

As we cannot predict the impacts of our actions, we often find out only after the fact that we over-exploited a given resource. For example, in the Atherton Tablelands of Far North Queensland, Australia, many homesteading farmers cleared all of the forests on their land, assuming that more open space would produce more pasture and more profits. They found instead that clearing forests right down to the edge of streams deprived them of valuable ecosystem services and reduced their profits. That is, ignorance led them to clear forests to the point that marginal net private benefits were negative. While this would have been a bad decision even in the absence of externalities, the downstream costs were also quite high. Many of these same farmers are now trying to restore their riparian areas at a dramatically higher cost than it took to clear them in the first place (Farley, 2000).

Missing markets

For a market to function optimally, everyone who would want to produce or consume the goods being marketed must be able to participate. For example, if the Mona Lisa were to be auctioned off and only people from Waco, Texas, were allowed to participate, it might not fetch as high a price as it would on the international market! Yet the fact is that future generations cannot possibly participate in today’s markets, and hence today’s market prices will not reflect their preferences. The market can therefore only 'efficiently' allocate resources if we assume that future generations have no rights whatsoever to the resources being allocated.

How we handle intergenerational gambles, particularly those with an unknown reward structures, is an ethical issue, but it would certainly seem that most ethical systems would demand at the very least that we do not risk catastrophic outcomes for the future in exchange for non-essential benefits today. Given our ignorance of ecosystem function, this means we would have to stay well back from any irreversible ecological thresholds. Such sustainability criteria would essentially distribute resources between generations, and the market could then function to allocate them within a generation.

Alternatively, we could just continue to act on the ethical assumptions of neoclassical economics. If we are indeed rational maximizers of self-interest, then the rights of future generations can safely be ignored. After all, as Kenneth Boulding once asked, what have future generations ever done for us?

Market Failures And The Efficient Allocation Of Natural Capital.

Now that we have laid out these specific market failures, our task is to understand how they affect the goods and services provided by natural capital. Specifically, we will look at fossil fuels, mineral resources, renewable resources, ecosystem services, waste absorption capacity and Ricardian land[10]. If a good is excludable, market allocation is possible. If a good is rival, production and consumption generate no externalities, prices respond to relative scarcity, and uncertainty is very low, then market allocation may also be efficient within the current generation. If the well-being of future generations is not affected by the use of the resource, then market allocation may also be intergenerationally fair. As we will see however, no good or service provided by nature comes close to meeting all of these criteria.

Fossil fuels

Fossil fuels are both rival and excludable, and thus can be allocated by market forces. However, the production and consumption of fossil fuels generates serious externalities at the local, regional and global levels. Examples of these externalities are categorized in table 4-2 according to their spatial and temporal characteristics. Because these externalities are so widespread, affecting not only virtually everyone in the world alive today but future generations as well, transaction costs for resolving these externalities through the market are infinite. In addition, fossil fuels are a non-renewable resource upon which, under current circumstances, the well being and even survival of future generations is highly dependent. Thus, if we allow unregulated markets to allocate these resources, the resulting allocation will be inefficient, and unfair as well if we believe that future generations have any rights to fossil fuels.

[10] Ricardian land is land as a physical space that receives rainfall and sunlight, and ignores the fertility, etc. of the land.

Externalities associated with fossil fuel use	Local	Regional	Global	Intergenerational
Global warming			X	X
Acid rain	x	X		X
Oil spills	X	X		x
Damage from mining (see Table 4-3)	X			X
War[11]	X	X		X
Water pollution	X	X		X
Soil pollution	X			X
Air pollution (gaseous)	X	X	x	x?
Air pollution (particulate)	X			

Table 4-2: Spatial and temporal characteristics of some of the externalities associated with fossil fuel extraction and consumption. Many of these externalities have different impacts at different spatial levels. A small x denotes relatively minor impacts.

Mineral resources

Mineral resources are also rival and excludable and therefore amenable to market allocation, but just as in the case of fossil fuels, their production and consumption generates serious externalities. As many of these negative externalities are less well known than those associated with fossil fuel use, we have summarized them in Table 4-3.

[11] The number of wars that have been fought and are currently being fought (e.g. in Angola) over control of fossil fuels argues for the treatment of war as an externality of fossil fuel production.

‘Externality’	What is it?	What does it affect?
Acid mine drainage	Metal sulfides are common in mineral ores and the associated rocks. When these rocks are mined and crushed, exposure to air and water oxidizes these sulfides, generating acids and toxic heavy metal cations.	Water required by the oxidation process also washes the products into nearby surface water and aquifers. In addition tot he well known affects of acidification (see Box somewhere on acid rain?) heavy metals build up in animal populations and humans.
Erosion and sedimentation	Heavy machinery, strip mines and open pit mines destroy surface vegetation which holds soils in place. Water washes away small particles from erosion and waste materials, depositing it elsewhere.	Major impacts are on wetlands and other aquatic habitats, but also affect soil organisms, vegetation, and restoration efforts.
Cyanide and other chemical releases	Cyanide and other toxic chemicals are regularly used to assist in extracting minerals.	Cyanide released into the ecosystem has adverse impacts on water, soil, aquatic, organisms, wildlife, waterfowl, and humans
Dust emissions	Ore crushing, conveyance of crushed ore, loading bins, blasting, mine and motor vehicle traffic, use of hauling roads, waste rock piles, windblown tailings, and disturbed areas all generate dust.	Dust can be an air pollutant, and may also transport toxic heavy metals.
Habitat modification	Mining can have dramatic impacts on the landscape, and uses enormous amounts of water.	Ecosystem structure and function are affected
Surface and ground water pollution	Mining uses massive quantities of water, pumping water from mines affects water tables, and mine wastes pollute water.	Altered surface and groundwater flows, with accompanying impacts on wetlands and other water dependent habitats.

Table 4-3: Production ‘Externalities’ of mineral resource extraction (specifically from hard rock mines). From EPA Office of Waste Water Management, Hardrock Mining: Environmental Impacts, http://www.epa.gov/owm/permits/hrmining/env.htm

Many of these externalities are fairly localized compared to problems from fossil fuel emissions, but can be very persistent. For example, acid mine drainage still occurs on mine sites worked by Romans over 1500 years ago. Over 500,000 abandoned mine sites exist in the USA alone (Center for Streamside Studies, no date). Again, transaction costs for resolving these externalities will be extremely high to infinite, depending on our concern for future generations, and cannot be resolved by unregulated markets.

It is worth noting here an interesting point. Within a generation, for the market to efficiently allocate resources, they must be rival. However, future generations cannot participate in today’s markets. Thus, if a good is rival *between* generations, i.e. use by one generation prohibits use by another, the market will still not allocate it efficiently because future generations cannot participate. Fossil fuels are rival between generations. Mineral resources, to the extent they can be recycled, are rival within a generation, but less so between generations. Thus, if mineral resources were efficiently recycled and had no negative externalities associated with their production and consumption, market allocation could be both intragenerationally efficient and intergenerationally fair.

Do prices reflect non-renewable resource scarcity?

The remaining serious problem with market allocation of non-renewable resources is the lack of information concerning remaining stocks and the ability of future technologies to develop cost effective substitutes.

Neoclassical economic theory generally assumes that prices increase as a function of scarcity. Using this assumption, Hotelling (1931) showed in a famous paper that the optimal rate of resource extraction was one at which increasing scarcity would drive the price up at the same rate as the returns on alternative investments. Empirically however, there is virtually no support for the Hotelling model (Devarajan and Fisher, 1981), and in fact most mineral resources have experienced declines in real prices over the past decades in spite of the unalterable fact that extraction has reduced the quantity of in ground stocks. This does not mean that prices do not reflect scarcity, as long as we assume that scarcity is defined not only by the physical quantity of a resource remaining, but also by the availability of substitutes. Prices equilibrate supply and demand, and if demand falls, scarcity is reduced, and prices fall as well. For example, fiber optic cables dramatically decreased the demand for copper in telephone lines explaining the fall in prices.

However, as recently as 1999, oil prices were very low in real terms relative to previous decades, yet oil consumption was near an all time high. It seems hard to argue that oil prices were low due to decreased physical scarcity of below ground stocks or due to greater availability of substitutes. Discovery of new oil supplies peaked in 1969. There is considerable debate even among the experts about the precise amount of oil left in the ground, and estimates of available reserves have changed dramatically over the years, often increasing (Campbell and Laherrère, 1998). If the experts do not know how much remains underground, how can prices tell us? It seems pretty clear that prices do not serve to equilibrate unknown in ground supply with demand, but rather they equilibrate the available above ground supply with demand. Available above ground supply is determined solely by the rate of extraction, which depends on known deposits, investment in infrastructure and available technological.

Economic analysis typically assumes that non-renewable resources will be mined from the purest, easiest to access sources first. As these are depleted, we then move on to sources that are more expensive to extract, again putting upward pressure on prices. However, there are two serious problems with this approach. First, of all, as Norgaard (1990) has noted, when we begin to exploit a new resource, we typically know very little about where the best fields are. A great deal of chance is involved with the initial discoveries. Norgaard compared this to the Mayflower. If people always exploited the best resources first, the first pilgrims would have settled on the best land in America. However, prior to their arrival, the pilgrims knew virtually nothing about land resources in North America, and ended up where they did largely by chance. As we exploit a new resource, we diminish the total stock, but we gradually acquire more and more information about where to find it and how to extract it, and more and more of the resource becomes accessible. Thus, there are two effects at work. The scarcity effect decreases the total amount of resource available, but the information effect increases the amount that is accessible and reduces the costs of extracting it. Thus, as long as the information effect is dominant, the price of the resource should decrease. Eventually however, the scarcity effect must come to dominate, and the price must then increase. Rather than predicting a gradual price increase in a resource, this model increases the potential for sudden, rapid increases (Reynolds, 1999). If we combine this analysis with the estimates of petroleum geologists, we would predict a sudden and dramatic increase in oil prices in the next 2-20 years.

This result is particularly important if we are concerned with sustainability. As we pointed out earlier, economists assume that price increases will trigger innovation and generate substitutes for any given resource. It is obvious though that developing substitutes requires technology, technological advance requires time, and the less warning we have of impending resource exhaustion, the less time there is to develop substitutes. While this argument is far from the only one discrediting the belief that we can ignore resource exhaustion, it is important.

Renewable resource stocks and flows

Renewable resources occur in the form of a stock (e.g. of trees or fish) that captures energy from the sun (perhaps via autotrophs or higher trophic levels), combines it with water and mineral resources, and creates a flow (of timber or fish). Stocks and flows are rival and potentially excludable, depending on whether or not institutions exist that can regulate access to them. If depleted at a rate no faster than they regenerate, they are non-rival between generations. This would seem to make them ideal candidates for market allocation. Unfortunately, unless we explicitly take future generations into account, economic incentives quite likely will lead us to deplete many of these resources faster than they can regenerate, and may eventually threaten them with extinction. What's more, as we have pointed out repeatedly, use of renewable resource stocks and flows unavoidably depletes ecosystem services as an 'externality' of their production. This dramatically complicates economic analysis of these resources.

Figure 1 shows the sustainable yield curve for a typical renewable resource. Sustainable yield is merely the growth rate (a flow variable) at a given level of stock. . Net growth is obviously zero at the origin, when the population is extinct. This curve also depicts a minimum viable population, at point CD, below which populations spontaneously decline (e.g. the last remaining mahogany trees in a forest are too far apart to cross pollinate, or the last remaining cod populations lack the genetic diversity to survive environmental change). When the population is at carrying capacity, point K, death rates are equal to growth rates, and net growth is zero. If we remove some stock, we increase resource availability for the remainder, and growth rates increase. If we remove too much stock, then breeding populations become insufficient to maintain high growth rates, and growth decreases. Harvests above the curve deplete the stock, and those below the curve allow it to increase, as indicated by the arrows.

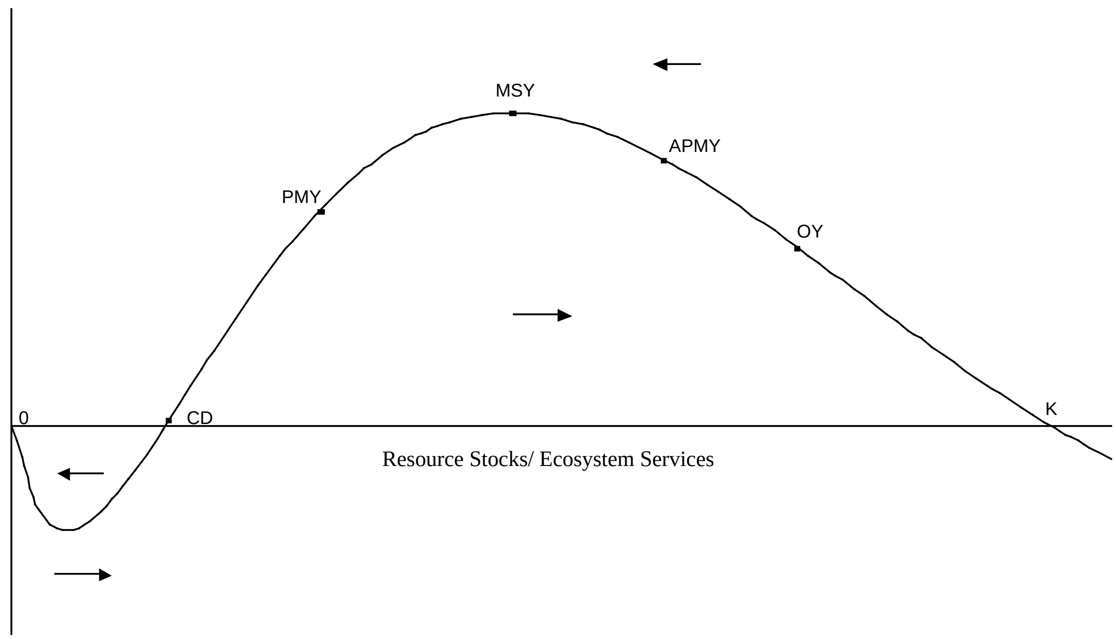

Figure 1: The sustainable yield/growth curve for the harvest of natural resources. Harvests on the curve are sustainable. Those above the curve deplete stocks, and those below the curve allow stocks to increase.

At first glance, it would appear that the goal of economists would simply be to make renewable resources as productive as possible. If this were the case, we should strive to maintain a population that produces the Maximum Sustainable Yield, or MSY—the same goal that resource managers might seek. However, this analysis is incomplete.

First, there are costs to harvesting, and these costs are likely to increase per unit harvested as the population in question grows smaller. Obviously, the smaller the population of fish that remains, the harder it is to catch. Even for forests, the most accessible timber will be harvested first, and as forest stocks decrease, it will cost more to bring the less accessible stocks to market. If the goal is to maximize total revenue minus total costs, increasing harvest costs will lead to a profit maximizing harvest at a larger stock than that which produces MSY. APMY in the figure indicates a possible annual profit maximizing yield. However, this analysis leaves the stock dimension out of our concept of total revenue—we are analyzing profit as a sustainable flow, not as the result of unsustainable stock reduction. Some stock reduction is necessary to arrive at the profit-maximizing stock, and the fish that are part of that stock reduction are also sold for a profit. In the neoclassical world, all resources are substitutable, and money is the perfect substitute for any resource. This means that the economic goal is not to maximize the harvest of any specific resource, nor even the sum of annual profits yielded by the resource. Rather, the market goal is to maximize net present value—the sum of <u>discounted</u> future profits from resource harvest and investment of revenue.

The number of fish harvested to reduce stocks is large relative to the annual growth. Those fish are sold. Stock reduction fish have the advantage of being available now—you don't have to wait for them to be hatched and grow. But the more you reduce the stock of fish today, beyond MSY, the fewer fish you will have tomorrow. The population of fish is like the proverbial goose that lays golden eggs in perpetuity. Surely no rational capitalist would kill such a productive goose. Or would she?

If the capitalist wanted to maximize the sum from now till the end of time of golden eggs, then obviously she would not kill the goose. But in the market everything is fungible. The goose also has a liquidation value as a cooked goose. Suppose the capitalist could kill the goose, cook it and sell it for a sum of money, which when put in the bank at the going interest rate would yield an annual sum greater than the value of the golden eggs? Then it is goodbye goose, hello bank!

How do resource growth rates compare to rates of return on alternative investments? One plot of redwoods in California has been monitored for over 70 years. This plot grows so rapidly that it is known as the 'wonder plot', yet the maximum this plot grew in any 10 year period was 3.5%, and the 70 year average was under 1%.[12]. In contrast, the average real growth rate of money on the stock market over the last 70 years was something like 7% per year (Johnson, 2001). Clearly, if our goal is to maximize profits, we should harvest the redwoods now and invest the money in the bank. Not surprising, all large stands of old growth redwoods under private ownership have now been harvested. In fact, for any species that is relatively inexpensive to harvest and grows slowly, profits are maximized by harvesting the species to extinction. In general, averaged over the time it takes to reach harvest size, many renewable resources grow quite slowly relative to alternative investments, and technology tends to reduce unit harvest costs over time[13]. If growth rates are sufficiently high for populations below the stock providing MSY, or if the costs of capture increase sufficiently, then the sustainable profit maximizing yield will be positive, but at a low level of stock that risks extinction from external shocks such as climate change. PMY in the figure indicates one possible profit maximizing yield.

The population growth rate of the goose (its egg-producing fecundity) is in direct competition with the interest rate, the "fecundity" of "barren " money, as Aristotle would have put it. But neoclassical economists say that Aristotle just didn't understand capitalism. Money itself may have no reproductive organs, but it is a surrogate for many other things that can reproduce, and on average those other things can reproduce faster than the goose. So the goose-killing, reinvesting capitalist has converted a slow-growing asset into a fast-growing one, and we are all therefore better off. So the story goes.

Now let's take the story a bit further in a thought experiment. Suppose an economy consisting only of renewable resources. The interest rate is equal to some weighted average of the growth rates of all renewable resource populations. Everything that grows more slowly than the average (the interest rate) is a candidate for extinction (unless at some stock its growth rate rises above the interest rate). But something is always below average. When the below average is eliminated what happens to the average in the next period? It goes up of course. The tendency, it seems, would be to end up with only the fastest growing species. Biodiversity would entirely

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[12] These figures were calculated by the authors from data provided in Allen, G; J. Lindquist, J. Melo, and J. Stuart (no date). Seventy-Two Years Growth On A Redwood Sample Plot: The Wonder Plot Revisited. Available on-line at http://www.cnr.berkeley.edu/~jleblanc/WWW/Redwood/rdwd-Seventy-.html

[13] Another mechanism can serve to make harvest costs negligible as well. When a resource is abundant, with stocks well above those that would supply maximum sustainable yield, it can make good economic sense to harvest large amounts fast. This requires investment in large amounts of harvest capacity. As populations decline, it makes sense to restrict harvests, but the industry retains the capacity to take very large harvests. Once the capacity exists, the cost of using that capacity may be negligible. To put these arguments in concrete terms, the technological ability to catch fish increased by 330% over a period in which landings per ton (catch rate) declined by 62%. Currently, the global fishing fleet has about 50% more capacity than is required for the world fishery resource (http://mac01.eps.pitt.edu/geoweb/courses/GEO1055/commons.html)

disappear. In a world in which everything is fungible that would not matter. We could all eat money! But we have forgotten prices. Surely prices would rise as particular slow growing species became scarce and the rising price would compensate for low biological growth rate, so that the value of the species would grow at a rate equal to the rate of interest before it became extinct. Yes, but remember that when the price goes up the price of the existing stock rises as well as the price of the flow of recruits. The incentive to liquidate the now more valuable remaining stock rises along with the incentive to increase the more valuable new recruits. What's more, harvest costs decrease relative to sales revenue, making it more lucrative to harvest even very scarce resources.

Bluefin Tuna provides an excellent example of this argument. Just this year (2001) a single 444-pound bluefin tuna sold in Japan for nearly $175,000, or about $395/lb. Although this was an anomaly, restaurants in Japan regularly pay up to $110 per pound for bluefin tuna (Schaeffer, 2001). Even if it cost $150,000 to catch a single fish, it would be well worth it. Admittedly this occurred under an open access regime, but there is neither theoretical nor empirical evidence that private ownership of the Bluefin would solve the problem. It is important to note that demand for essential goods or those with few substitutes is generally inelastic, and thus the more essential a good is, or the fewer substitutes available, the more likely that price increases accompanying increasing scarcity will make it profitable to drive the resource to extinction!

This is only a thought experiment, not a theorem or an empirical demonstration. But it uncovers a disturbing, self-defeating logic. Furthermore, our thought experiment treated species as market goods, neglecting entirely the ecosystem services each species provides, and the externalities associated with their harvest, which is precisely the problem with real life markets. It also ignored competitive pressure from the exploitation of <u>nonrenewable resources</u>, a pressure that tends to raise the interest rate. If we deplete nonrenewables as fast as we can, then in effect species will have to compete with a "growth rate" that is really a depletion rate pushed ever higher by new extractive technology, at least in the short run, which is all it takes for extinction. How could whales reproduce fast enough for whale oil to compete with the rapid depletion of large reserves of petroleum, even if whales were private property?

Ecosystem services

The analysis of optimal harvests of renewable resources so far has only treated them as stocks and flows of raw materials. Yet renewable resources also provide ecosystem services, and we cannot ignore one when deciding how best to allocate the other. While natural resource stocks and flows have some characteristics of market goods, the services they generate typically do not. Such services are generally pure public goods, and markets offer no incentives to produce or preserve them.

Treating the destruction of ecosystem services as a negative externality of all economic production suggests the possibility of internalizing this cost into all economic decisions, but to do so 'optimally' would require fairly precise values. Yet these services are characterized at best by uncertainty (we know the possible outcomes of damage to ecosystem funds on ecosystem services, but don't know the probabilities) and more often than not by ignorance (we don't even know the range of possible outcomes). In addition, the value of all externalities would need to be worked out by economists, ecologists and others, and incorporated into the prices of the goods that generate the externalities. And of course, the marginal value of an ecosystem service changes along with the supply of the ecosystem service, so the value of externalities would be constantly changing. As we have pointed out, all economic production incurs externalities. The notion of calculating the constantly changing values of all externalities for all goods would be a Promethean task. After this was achieved, it would still require some institution to collect the externality fees. Even then, this would not be a market solution in the strict sense, unless the individuals who suffered from the externalities were compensated to the extent they suffered— which itself brings up a potential for inefficiency as people compensated for externalities would be indifferent about subjecting themselves to those externalities (Verhoef, 1999). And we must remember that the magic of the market is precisely its unplanned, decentralized nature, and its ability to utilize “knowledge not given to anyone in its totality” (Hayek, 1945). Effectively internalizing externalities in contrast requires precisely the opposite-- centralized planning by individuals provided with knowledge in its totality.

Another issue is the likelihood of time lags between destruction or degradation of the ecosystem funds and interruption in the services they supply. Either internalizing externalities must account for externalities to future generations, or the current generation will be tempted to leave less than is desirable for the future, as intergenerational market transactions have infinite transaction costs. In short, there appears to be simply no way we can rely on the market alone to allocate ecosystem services.

Though we know the market alone won’t get us there, can we say anything about the optimal level of renewable resource stock that generates valuable ecosystem services? Ecosystem services are presumably a continuously increasing function of ecosystem stocks. Roughly speaking then, optimal harvests of stocks is solely a function of flow (the Y-axis in figure 1) while optimal harvest from a stock that simultaneously generates services is a function of both stock and flow (the X and Y axes). Therefore, the optimal level of resources for generating raw materials (goods) and services will always be higher than when optimizing for raw materials alone, and unregulated markets will always lead to over-exploitation of renewable resources. The larger stocks necessary to provide the optimal yield of goods and services will also be less susceptible to extinction from unexpected shocks such as disease or climate change. On figure 1, OY indicates one possibility for optimal yield.

Waste Absorption capacity

Waste absorption capacity is really just another ecosystem service. We treat it separately here because it is extremely important and because it has different characteristics from most other ecosystem services. Waste absorption capacity is the ability of the ecosystem to absorb and process pollution, and the economics of pollution is the central focus of neoclassical environmental economics. Unlike most ecosystem services, waste absorption is a rival good. If I dispose of my sewage in a wetland, there is less capacity subsequently for that wetland to process someone else’s wastes. In many countries, various institutions are being put into place that make waste absorption capacity an excludable good. Examples range from regulations such as direct limits on industrial emissions and mandatory catalytic converters in cars to tradable emissions permits for sulfur oxides. This means that waste absorption capacity can be treated as a private good if we create tradable permits or quotas in pollution rights.

However, just because we can create markets in pollution does not mean that these markets will lead to efficient allocation. Rather, all we can hope for is a cost effective allocation. A cost-effective allocation is one where we achieve a given level of output as inexpensively as possible. Each individual polluter will pollute as long as the benefits of polluting are greater than the costs of purchasing another pollution unit permit or paying a pollution tax, which will equate marginal pollution benefits across polluters. This is the necessary condition for cost minimization. If we meet the marginal cost equals marginal benefit rule, why do we say that this approach is only cost effective and not efficient? The costs and benefits we are discussing here are the monetary costs of polluting. As pollution is a pure externality, we must recognize that polluters entirely ignore the marginal external costs of their pollution, which is why permits were issued in the first place. Efficiency will only result if the number of permits is such that the marginal external costs (MEC) of pollution are just equal to the marginal social benefits. There is of course no direct social benefit to pollution per se, but as we have repeatedly stated, all productive processes generate some pollution, and if we prohibit all pollution, we virtually prohibit production.. The problem is of course that our knowledge of external costs of pollution is characterized predominantly by ignorance and uncertainty, to a lesser extent by risk, and to a minimal extent by certainty. For most pollutants, we do not know what impact they have on ecosystem services, we do not the impact they have on human well-being, and we do not know the capacity of the ecosystem to absorb waste[14]. And many costs of pollution only become evident after many years. Since we do not know the full social costs of pollution, we cannot set the level of permits such that they balance costs with benefits. Policy makers are also not well informed concerning the marginal benefits of pollution to polluters. Thus, we are only likely to achieve an efficient pollution outcome by pure chance.

Some economists might argue that pollution permits can lead to optimal outcomes, because those who desire less pollution can purchase the permits then destroy them. However, destroying permits provides public goods, and we cannot count on individuals to supply appropriate amounts of public goods.

We must also stress the importance of looking at pollution flows and waste absorption capacities as dynamic. If a flow of waste is larger than the capacity of the ecosystem to absorb it, then it will accumulate. As it accumulates, it damages ecosystem functions, resulting in a reduced capacity to absorb waste. Over time, the accumulating waste will destroy almost all ecosystem services, resulting in unacceptable loss to any humans that depend on these services. Yet at least one well know text in natural resource and environmental economics assumes that pollution causes zero damage before overwhelming the waste absorption capacity, because the ecosystem is capable of assimilating the waste (Pearce and Turner, 1990). This could not stand in greater contrast to our argument that there are costs to pollution even when flow can be absorbed, and that costs approach infinite when waste flows exceed absorption capacity.

Finally, we must stress that even if policy makers could measure the full marginal costs and benefits of pollution and set the number of permits accordingly, pollution markets would still fail to generate all the wonderful properties associated with the free market. Different individuals obviously have different preferences (utilities) with respect to polluted environments. Markets are so widely extolled because they allow the individual to choose what she produces and consumes so that her marginal benefits from either are exactly equal to her marginal costs. Pollution however affects public goods, and all individuals must consume the same amount. It would be impossibly complex to create a system in which each individual was paid by the polluter according to his or her own dislike of pollution. This by no means implies we are opposed to marketable permits or pollution taxes, but it does mean that we should not associate with them all the market virtues associated with the buying and selling of market goods.

[14] We should also note that waste absorption capacity is dynamic. As pollutants flood into an ecosystem, some organisms will die out, and others will thrive. The change in the ecosystem affects its capacity to process waste.

Ricardian Land

The final generator of goods and services we will consider is Ricardian land. By Ricardian land we mean land simply as a physical space capable of capturing sunshine and rainfall, and not the various productive qualities inherent to the land itself. Within a generation, land is both rival and excludable, and hence can be allocated by markets. Between generations, it is non-rival, which suggests market allocation of land might meet the criterion both for efficiency within a generation and fairness between generations. Before we reach this conclusion, however, we must ask what is it that makes Ricardian land valuable? Certainly in market terms, the most valuable land in the world is found within the borders of big cities, where prices may pass $100,000 per square meter, and the least valuable land is generally found in the most deserted areas. What makes land valuable then would appear to be the proximity to other humans. Some might reply that the low value of land in uninhabited areas is due to other factors, such as extreme cold or extreme heat, and those same factors prevented people from settling there in the first place. But if we look at some of our planet's less inviting habitats, we find that where they are inhabited, land prices are highest at the sites of densest habitation, and lowest where population is thinnest, even if the sites are otherwise virtually identical. The fact is that land attains value as a positive externality of the decisions of others. Land values thus result from a market failure, and we cannot simply assume that markets are the best means for allocating Ricardian land[15].

In addition to the market failure associated with land values, there is another reason why the market magic does not work with land. Land is present in a fixed amount, regardless of price. The supply of land will not fall if prices decrease, and will not grow if prices increase. With growing populations and growing wealth on an increasingly full planet, the steady trend is for land values to increase. Thus, whoever manages to acquire land will in general see the value of that land grow through no effort of her own. This makes land an excellent store of wealth subject to speculative investment. Land purchased for speculation is often left idle, but the demand for land for speculative purposes must be added to demand for land for productive purposes, driving up the price, and reducing the ability of people to buy land for production. In other words, under certain circumstances, markets in land can reduce the production from land. None of this means that land ownership and land markets are necessarily bad—it simply means that we should not automatically attribute all the theoretical virtues of markets to markets in land.

Table 3 summarizes some of the important characteristics of these seven types of goods and services for comparison.

[15] For a convincing defense of this argument, Henry George's Progress and Poverty, or George, H. (1928). Significant paragraphs from Henry George's Progress and poverty, with introduction by John Dewey. Doubleday, Doran and company, inc. Garden City, N.Y

Class of good or service	excludability	'rivalness'	degree and type of uncertainty	Externalities	Price reflects scarcity
fossil fuels	excludable	rival	moderate risk concerning total stocks	Pervasive negative	No
minerals	excludable	rival, but only partially so between generations	moderate risk concerning total stocks	Pervasive negative	No
renewable resources	excludable	Rival, but potentially non-rival between generations	varies: lower risk for plant stocks, higher risk for animal stocks. Renewability characterized by uncertainty.	Pervasive negative	Partially
ecosystem services	primarily non-excludable	primarily non-rival	High uncertainty and ignorance in all respects: what they are, how they are provided, and degree of resilience to human activities	none	No price
waste absorption capacity	can be made excludable	rival	High uncertainty and ignorance in all respects	Pervasive negative	If regulated
Ricardian land	excludable	rival, but not between generations	virtually none (sea level rise)	Pervasive positive	Yes, but will not lead to substitutes or increased supply

Table 3: Select characteristics of different types of goods and services relevant to allocation. Missing markets are a serious problem for all resources rival between generations.

Summary and Conclusions

The market system has shown itself to be tremendously effective in creating consumer goods, leading to unprecedented levels of material consumption. This success, accompanied by the dramatic collapse of the Soviet system, has lead to the ideological conviction that markets are the most effective system possible for allocating resources. The dominant capitalist countries aggressively promote this ideology. As a result, almost all countries on the planet have adopted or are in the process of adopting market mechanisms for allocating scarce resources. Global trade is also growing at an unprecedented rate, further extending the scope of the market. In a universe subject to the laws of the thermodynamics, human made goods can only be produced through the transformation of natural capital, and as these goods wear out, they must return to the ecosystem as waste. Inevitably, then, increased production of human made artifacts facilitated by markets depletes natural capital, and changes the relative scarcity of the two.

Unfortunately, as we have shown in this paper, fundamental properties of natural capital mean that market mechanisms are not effective for its allocation. Specifically, use of natural capital is characterized by pervasive externalities, many of the critically important services generated by natural capital are non-excludable and or non-rival, we do not know the full impact of our actions on natural capital, and markets ignore the preferences of future generations. On a full planet, externalities increase simply because more people are exposed to them, and the worst externalities destroy public good services of intact ecosystems.

There is insufficient space to provide detailed exposition of the types of allocative systems that would function better than markets for allocating natural capital, but we can briefly outline some important features. Markets depend on atomization—each individual acting in his own self interest generates a supposedly 'optimal' outcome (Bromley, 1993). In contrast, fundamental properties of natural capital means its allocation is best handled by integrated social units. In the case of public goods, this is obvious. Externalities are readily solved by integration. For example, the externality between a coal utility and a laundry would be optimally resolved if both enterprises were owned by the same individual (Bromley, 1993). There is little incentive for individuals to resolve uncertainties that affect others, and insufficient incentives for individuals to generate technologies that preserve and create public goods. Therefore, on a full planet, the market is unlikely to be the best system for allocating scarce resources among alternative ends.

This is not to say that markets cannot aid in the allocation of such resources, but it does mean that we cannot automatically assume that markets are the most efficient mechanism available for all resources at all times. On a full planet, where everyone's impacts are increasing felt by others, efficient allocative mechanisms must focus on cooperation, not competition; integration, not atomization. We must seek to rebuild common property regimes, in which resources that benefit all are controlled by all, and can learn much from the institutions of pre-capitalist societies. The need for integration places important new political demands on society as well, as many of the most important resources ignore political boundaries. Institutions must be on the scale of the problem they address.\

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