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Analysis

The production and allocation of information as a good that is enhanced with increased use

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ABSTRACT

Information has some unique characteristics. Unlike most other goods and services, it is neither rival (use by one prevents use by others) nor non-rival (use by one does not affect use by others), but is enhanced with increased use, or 'additive'. Therefore a unique allocation system for both the production and consumption of information is needed. Under the current market-based allocation system, production of information is often limited through the exclusive rights produced by patents and copyrights. This limits scientists' ability to share and build on each other's knowledge. We break the problem down into three separate questions: (1) do markets generate the type of information most important for modern society? (2) are markets the most appropriate institution for producing that information? and (3) once information is produced, are markets the most effective way of maximizing the social value of that information? We conclude that systematic market failures make it unlikely that markets will generate the most important types of information, while the unique characteristics of information reduce the cost-effectiveness of markets in generating information and in maximizing its social value. We then discuss alternative methods that do not have these shortcomings, and that would lead to greater overall economic efficiency, social justice and ecological sustainability. These methods include monetary prizes, publicly funded research from which the produced information is released into the public domain, and status driven incentive structures like those in academia and the "open-source" community.

1. Introduction

We live in the age of information and global markets. Markets play an important role in the generation and distribution of new information. They decide on what information to produce, which scarce resources are allocated towards that production (e.g. scientists, laboratory equipment, computers and so on), and once produced, who can use it. Governments and universities also play an important role in the generation of new information; however, through the passing of the Bayh–Dole act in recent decades, the U.S. government has pushed academic centers to produce information with commercial applications (Sampat, 2006) (Fig. 1). Before such change in priorities and throughout much of the 20th century, universities avoided direct involvement with copyrights and patents. Universities now are patenting and copyrighting new information at an unprecedented rate (Fig. 2).

Society increasingly relies on markets to produce and allocate information. At the same time, society also faces a number of serious problems that may be unsolvable without new information to generate new technologies. For example, many experts believe that if we fail to reduce CO_2 emissions by less than 80%, atmospheric carbon stocks will continue to climb, resulting in runaway climate change and ecological catastrophe. However, our society is currently so dependent on fossil fuels that reducing emissions by 80% could result in mass starvation and economic collapse. In economists' terms, the marginal costs of CO_2 emissions (the supply curve) fail to intersect with the marginal benefits of fossil fuel use (the demand curve), and there is no economic solution to the climate change problem with current technologies. Given the urgency of climate change and other critical problems which information can help to solve, it behooves us to closely examine the effectiveness of markets in producing and allocating information.

There is a vast literature regarding the economic market's inability to efficiently produce and allocate information (Foxon, 2003; Stern, 2006). On the allocation side, a market's maximum efficiency is when the marginal cost of producing a good equals its marginal benefit and price. Since the marginal cost using existing information is negligible, efficiency demands that the price also be negligible, and any higher price creates a dead-weight loss in society, reducing efficiency. Paradoxically, the economic surplus from information, which is essentially the monetary value of the total use of that information, is maximized when the price is essentially zero (Daly and Farley, 2003).

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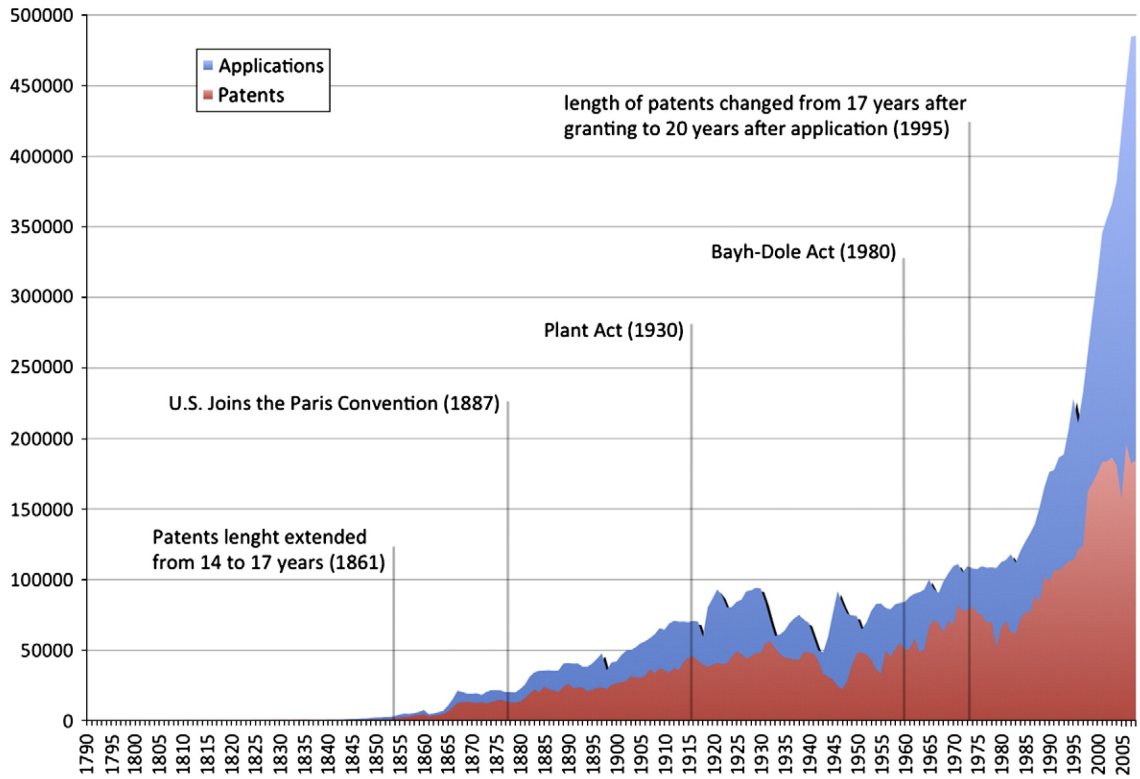

Fig. 1. Annual U.S. patent activity since 1790 until present and the various policy changes influencing patents.
Source: U.S. Patent and Trademark Office.

However, at a price of zero the market will not produce information. On the production side, it can be difficult to make information excludable, which in turn makes it difficult to sell. If those who produce information cannot recoup at least the costs of production, they are unlikely to produce it (Arrow, 1962). If information is not created in the first place, it of course generates zero economic surplus.

In the 1970s, Rothschild and Stiglitz (1976) showed that markets for information suffer from a paradox. For a market to function efficiently, all parties must understand the nature and effects of the good or service being traded to the fullest extent possible. There must be complete information. However, if a buyer of information were to have access to a piece of information before the transaction occurs, there would be no protection for the seller if the buyer decided to utilize that information without paying. Without complete knowledge of the information before the transaction, the transaction cannot be completely efficient, but if the information itself is the good or service being traded then it is impossible

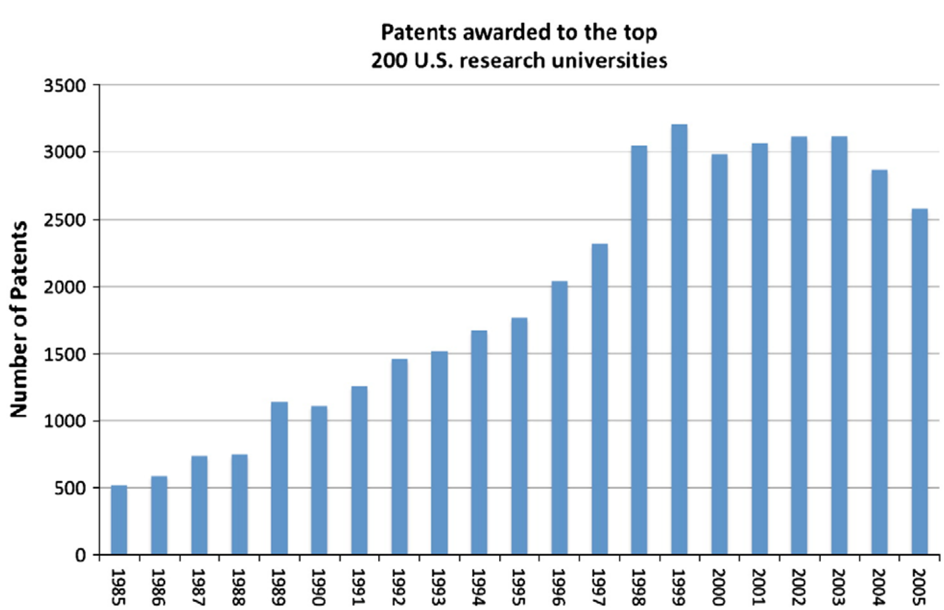

Fig. 2. Number of patents assigned annually to U.S. colleges and universities ranked in the top 200 by R&D expenditures in FY 2004.
Source: U.S. Patent and Trademark Office.

to make it both excludable and the trade efficient at the same time (Greenwald and Stiglitz, 1986). Nonetheless, a reduction in economic surplus is preferable to no economic surplus, which has led most market economies to create intellectual property rights (IPRs) to information in the form of patents and copyrights. IPRs provide incentives for the production of information, but in exchange create artificial scarcity and inefficiencies in consumption for the duration of the patent or copyright.

Unfortunately, IPRs fail to solve the production problem, because they are inevitably incomplete. New technologies build on old ones regardless of IPRs through reverse engineering or illegal copying. Information generates positive externalities, and hence tends to be underprovided by markets (Arrow, 1962). One strategy to addressing this problem is through stronger IPRs, as promoted by the World Trade Organization, allowing a greater return on investment by firms in developed countries (Park and Lippoldt, 2008). A second strategy, justified by the positive externalities of information production, is to lower R&D costs by publicly funding or subsidizing R&D while still allowing firms to patent and sell the resulting technologies. Almost all market economies currently provide at least some public support for R&D (Deutch, 2005; Stern et al., 2006). A third strategy is to recognize the additive nature of information, and manage it as a global public good, with publicly funded production and open access consumption (Stiglitz, 1999a,b; Bollier, 2003; Daly and Farley, 2004).

In this paper, we argue that the changing nature of the problems that global society confronts has increased the disadvantages of using conventional markets to produce and allocate information. The market is unable to meet society's desirable ends and creates a system which encourages competition instead of collaboration, decreasing the opportunity for innovation. Alternative institutions may be better equipped for managing the flow of information. Information should therefore be managed, as Stiglitz suggests, as a global public good.

Originally, when the current economic paradigm was created, with its assumptions and conventions, material wealth was the limiting factor to improving well-being. That has now changed in many countries, where there is an excess of material goods, but a poor distribution of those goods and a dearth of social and natural capital (Beddoe et al., 2009). This has become a global problem that requires global information exchange to solve. And yet this paradigm has persisted due to a lack of alternative options and the benefits it provides to a key minority (Stiglitz, 2002). We are now using the market to deal with completely different problems, and need information that is no longer revolving around material production and consumption, but around solving global public goods problems on the social and natural level. The development and the allocation of this type of information for a greater social good have a different level of responsibility associated with it. It requires that the focus be placed on the social good instead of the private gain.

Economics is conventionally defined as the allocation of scarce resources among alternative desirable ends. This definition can guide us as we assess the effectiveness of markets for allocating information. It follows from the definition that the first task is to determine the desirable ends of economic activity, or in our case, the most desirable ends we should pursue through the creation of new information. We must then assess the characteristics of information relevant to allocation. Only then can we decide if markets generate the type of information most important for modern society, if they are the most cost-effective mechanism for producing that information, and once the information is produced, if they are the most effective mechanisms for maximizing the value of that information. We explain our methods for assessing each of these criteria as we proceed.

This paper shows that much literature exists on the shortcomings of markets when dealing with the production and allocation of information. The literature also attempts to identify means of altering the economic market in such a fashion as to allow for greater revenue or efficiency. However, the majority of the methods suggested work within the market and try to protect market goods. In this paper we recognize that information needs to be treated as a public good that improves with use. Hence, this requires alternative institutions to manage it and achieve society's desirable ends.

2. Desirable Ends of Information

Human culture is based on information, as is all economic production, making information essential in attaining virtually all desirable ends. Conventional economic theory is based on marginal analysis, posing the question of what types of new information are most important at the margin (Daly and Farley, 2003). In other words, what types of new information would generate the greatest improvements in human welfare at the lowest cost. While this is inevitably a somewhat subjective question, certain issues that dominate the global headlines seem to suggest some likely answers. We will focus on those that concern resources absolutely essential to human well-being, such as energy, food, biological diversity, water, shelter, sanitation, and medical treatment, to name a few.

Energy is an essential component to all economic production. Modern society is exceptionally dependent on abundant and cheap fossil fuels, a finite resource. Oil is currently the most important fossil fuel. Oil discoveries peaked in the early 1960s, and production surpassed discoveries in the early 1980s. Humans are currently using several times as much oil yearly as they discover. Eventually, supplies will not be able to keep up with rising demand, and we are likely to see an end to the era of abundant and cheap oil. Skyrocketing oil prices and diminishing reserves could play havoc on our economic system (Campbell and Laherrere, 1998; Deffeyes and Silverman, 2004; Heinberg, 2005).

Fossil fuels also threaten to wreak havoc on our global climate by releasing massive quantities of carbon dioxide. The Intergovernmental Panel on Climate Change (IPCC) suggests that unless we reduce carbon emissions by 80% by 2050, we will risk catastrophic climate change (IPCC, 2007). Hansen and Sato (2008) suggest that CO_2 levels exceeding 350 parts per million (ppm) threaten catastrophic change and calls for even tighter restrictions, current levels have exceeded 385 ppm (Tans, 2009). Allocating information towards the discovery and production of new carbon neutral energy alternatives seems highly desirable. And yet, we continue to limit access to technologies that may help us avoid causing further irreparable damage (Fig. 3).

The most serious threat of climate change is to global food production—agriculture emerged at the start of the Holocene, a 10,000 year period during which average annual global temperature stayed within a very narrow band (Costanza et al., 2007). Most experts believe that we are already committed to a certain level of climate change, and adaptation is essential. We will need to develop new agricultural crops and new farming techniques and technologies, or potentially revisit old ones, to continue to feed our growing population. Allocating information towards these new agricultural technologies also seems highly desirable.

A third issue is the provision of life sustaining ecosystem services, upon which humans depend for their survival. One of the greatest threats to ecosystem services is biodiversity collapse; as the Millennium Ecosystem Assessment (2006) concludes, biodiversity sustains all ecosystem services, yet species are currently going extinct at 100–1000 times the background rate. The major causes of biodiversity loss include fragmentation, habitat degradation and loss, pollution, over-exploitation of natural resources, invasive species, and climate change. The leading cause of fragmentation and habitat loss is agriculture. Therefore carbon free energy and new agricultural technologies are essential to sustaining biodiversity. To stem natural resource depletion, we will also need technologies that generate more human well-being using fewer resources and generating less waste.

3. Nature of Information and Associated Markets

As a resource, information has unique characteristics that affect its allocation. Conventional market resources are rival, or subtractive: one person's use leaves everyone else less to use. For example, if one person

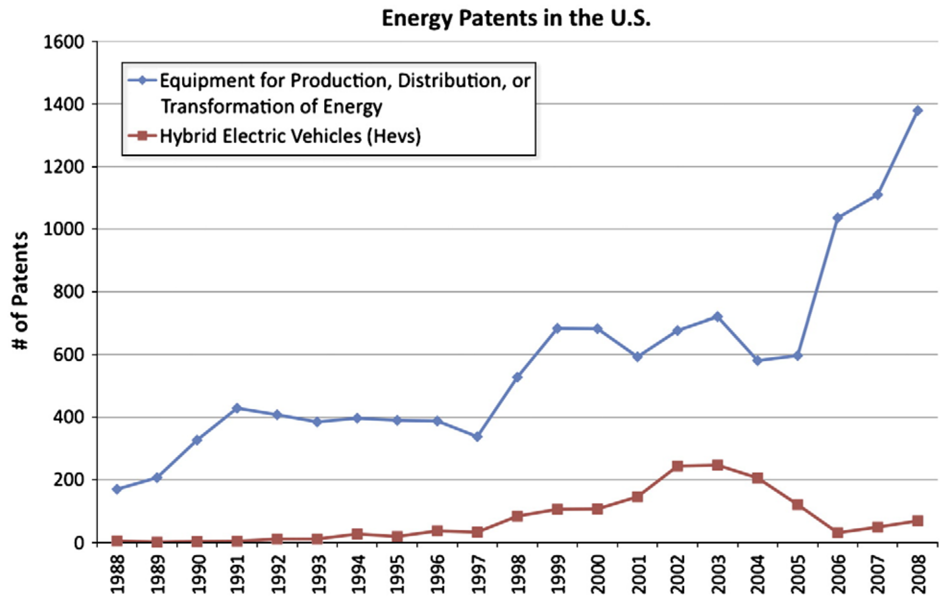

Fig. 3. Annual U.S. patents granted in the 'Equipment for Production, Distribution, or Transformation of Energy' (D13) and 'Hybrid Electric Vehicles' (903) USPTO classes. Source: U.S. Patent and Trademark Office.

cuts down a tree to build furniture, it is no longer available for someone else to build a house. Information is a different type of resource. If information is used by one person, it does not leave less for anyone else to use. No matter how many people read this paragraph, there will be no less information left for anybody else. Economists refer to such resources as "non-rival". However, the resource of information is not just non-rival, but actually improves through use. The term "additive" can be used to describe a resource that improves through use, such as open-source software (Weber, 2000; Lessig, 2003). After reading this paper you may develop new and better ideas from which we may all benefit in the future.

Diamond (2005) suggests that the additive nature of information accelerated the development of technologies and civilizations. Technological progress was exceptionally slow when human populations were primarily small bands of hunter–gatherers roaming the countryside. Once agriculture evolved allowing greater population densities, ideas began to circulate faster, leading to a faster rate of technological advance. Written language emerged allowing for ideas to be stored and communicated more easily and more rapidly, further accelerating technological advance. Mercantilism and industrialization led to yet more rapid communication of ideas across greater distances, contributing to an even more rapid rate of increase in knowledge. A recent biography of Genghis Khan (Weatherford, 2005) offers an additional example. As Khan conquered the known world, he adopted new technologies from conquered lands and spread them across his empire. Having united most of Asia, the Middle East, and Eastern Europe, Khan opened and protected trade routes, allowing for the free exchange of people and ideas throughout the empire. Weatherford argues that this spread of information ultimately paved the way for the European Renaissance and the industrial revolution. Recently, the phrase anticommons was coined in reference to patents that slow the rate of advance of new information (Heller, 1998a,b; Heller and Eisenberg, 1998a,b).

Information is a natural monopoly which has high fixed costs and low marginal costs. For example, it took approximately $10 billion to develop Windows Vista (Takahashi, 2006), a fixed cost which would not change whether one computer ran Vista or 1 million ran it. The relevant marginal cost for Vista is the cost of burning a CD and installing it on one additional computer, which is negligible. If only one thousand people used vista, it would have to sell for $1 million a copy for Microsoft to break-even. If instead 100 million people use vista, Microsoft could sell it for $100 a copy and break-even. The more people that use a non-rival good or service, the lower a price it can be sold for. However, competitive markets only work when large numbers of vendors sell nearly identical products. While monopolists in theory could sell the product at the lowest possible cost and still break-even, monopolists in practice maximize profits by producing less and charging a higher price (Daly and Farley, 2003). As a result, many economists argue that natural monopolies should be publicly owned or regulated. In the case of information, the solution would be public provision.

Most economists assume that markets reveal the desired ends of economic activity through market demand as manifested in purchase decisions, then efficiently allocate the scarce resources necessary to achieve those ends (Costanza and Farley, 2007). But what is economic demand? Economic demand is preferences weighted by income, implying that those with no income have no demand. For example, this implication states that very little demand exists for life saving cures for contagious diseases that affect poor people since they do not have the income to pay high prices for those cures. Economic markets also only reveal demand for marketed goods and services. Only privately owned goods and services can be marketed, making private property rights a pre-requisite for conventional markets to function. However, many important goods and services are, in practice, "non-excludable" and cannot be effectively privately owned. For example, if a technology to restore the ozone layer is developed, the use of the restored ozone layer cannot be restricted to individuals who pay for its restoration. Within such a system, no market incentives exist to pay for the services and creates no market demand for such services. Conventional economic markets therefore lack the incentives to create information required to cure contagious diseases affecting the poor or to preserve ecosystem services.

An example can clarify how markets decide which information to produce and how to allocate it. In the 1970s, Aventis, a pharmaceutical company, began developing a compound called eflornithine as a potential anti-cancer drug. During the development process the drug was also found to remove hair and treat human African trypanosomiasis (HAT), or African sleeping sickness, a contagious and debilitating disease endemic in Africa (McNeil, 2001). However, when in 1995, the drug was found to have no affect on cancer, Aventis halted production including the forms of the drug that cured sleeping sickness. At the time, much of central Africa was war-torn, the population requiring the drug was unable to pay for it, meaning that no economic demand existed and hence, there was no interest from Aventis to produce it. A few years later another pharmaceutical company, Bristol-Myers Squibb (BMS), began producing a form of this same compound as a facial hair removal cream for women. This again created an economic demand because now rich women were willing to pay large sums for this cream. Once the production resumed, the World Health Organization (WHO) and Doctors Without Borders were able to convince BMS to donate 5 years of the drug to patients in Africa. This move also persuaded Aventis and Bayer to donate $5 million a year for monitoring, treatment, and research and development (Wickware, 2002). Patents on drugs and surgery related techniques and technologies have become increasingly popular in the past two decades (Fig. 4). Since 1988, over 145,000 patents have been granted in the United States alone on drugs and bio-affecting and body treating compositions. Net sales and expenditures by the companies have also increased in the past decade (Fig. 5). In 2007 alone, net sales from pharmaceuticals and medicines were over $350 billion.

This example shows how economic market forces can allocate scientist's efforts towards producing luxury goods instead of basic necessities for the poor. Scientists, unlike information, are a rival resource, if one is hired to develop cosmetics for the rich, they are no longer available to work on life saving cures for the poor. Although economic markets are accepted as the deciding mechanism for society's ends, if asked directly, most of the population would presumably rank developing life saving cures as a more desirable end for society than removing women's facial hair.

4. Allocation

4.1. Production Side

Are markets the most cost-effective way to produce information? Do markets generate the most desirable types of information?

The production of new information requires the allocation of scarce and rival resources as inputs into innovation, as well as existing knowledge which is neither scarce nor rival. However, for the scarce resources to be allocated properly, an incentive structure has to be in place to encourage the development of the desired information in a productive and efficient way. This section discusses the current incentive structure, productivity of the creation of new information, and efficient allocation of scarce resources toward the production of information.

The first issue is productivity. In the private sector, the goal is to develop a patentable (i.e. excludable) product. Firms therefore jealously guard their knowledge, refusing to share it with competing firms. There may be dozens of pharmaceutical firms striving to develop a new treatment for obesity, each with its own team of research scientists strictly forbidden from sharing their knowledge with others. This is a counter-productive methodology. One of the reasons that Silicon Valley generated such a wealth of new ideas was the intellectual density of the area. Scientist and researchers living in close proximity exchanged ideas in bars and at parties, but there was also a constant movement of employees and skills, providing a means of integrating all the information (Dennis, 2008), in spite of the remaining barriers to information sharing imposed by firms. This example serves to illustrate the fundamental additive characteristic of information, the more it is shared, the faster it will improve (Stiglitz, 1999a,b). Such a research structure creates the question of which is a more effective research model—100 individual scientists unable to communicate with each other, or 10 teams of 10 scientists allowed to communicate freely within their groups? All work done by a scientist is the extension of research done by others throughout history (Scotchmer, 1991; Heller, 1998a,b; Stern et al., 2006). Without such passing down of knowledge, no progress would be made. The inability of current scientists to freely exchange new information significantly reduces overall productivity.

Most academic researchers guard their data and ideas prior to publication; nevertheless, the driving goal is the publication of their work, i.e. to share their knowledge. Although a trend has recently evolved in certain academic fields to patent (Fig. 2), many scientists attempt to do both, patent a commercializable idea and publish the general idea. A recent study found publications having associated patents receive fewer citations then those publications with no associated patents, and this affect becomes more pronounced with the number of years elapsed since date of the patent grant (Murray and Stern, 2007). This is due to the additional transaction costs and bureaucracy required to cite and use patented information; scientists choose not to cite it, reducing the overall societal exchange of information (Barton, 2000).

Other productivity issues arise from patents. Patent trolling occurs when a private firm, also known as a non-practicing entity (NPE), buys up patents with no intention of utilizing the information but with the intention of demanding royalties from anyone attempting to use the information or to sit on the patent until it can be sold for a profit. In both cases, the only result is a higher price on the information. Resource allocated to the sole purpose of limiting the exchange of information creates social inefficient, and in economics terms is known as rent-seeking

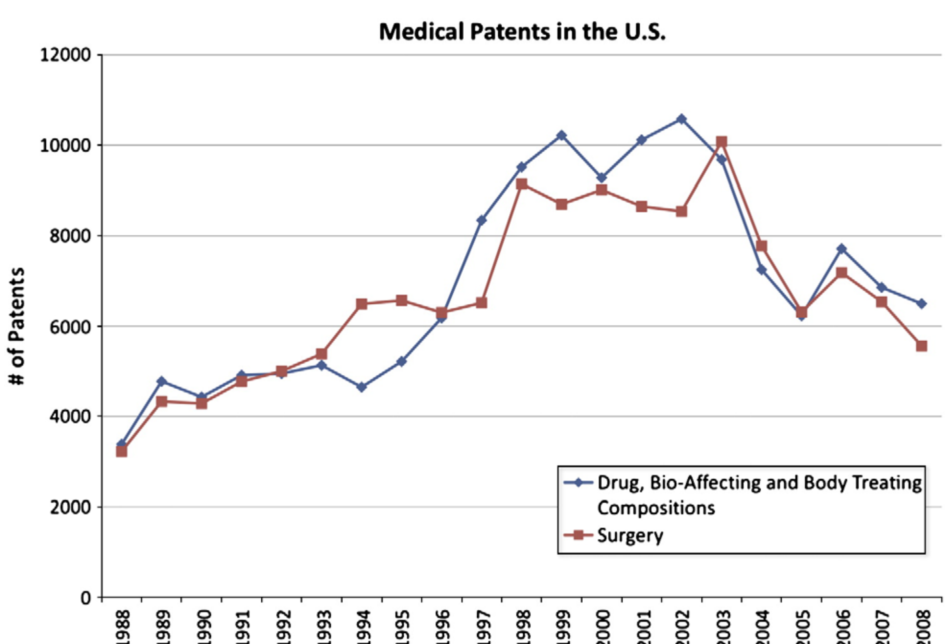

Fig. 4. Annual U.S. patents granted in the 'Drug, Bio-Affecting and Body Treating Compositions' (424 and 514) and 'Surgery' (128, 600, 601, 602, 604, 606, and 607) USPTO classes. Source: U.S. Patent and Trademark Office.

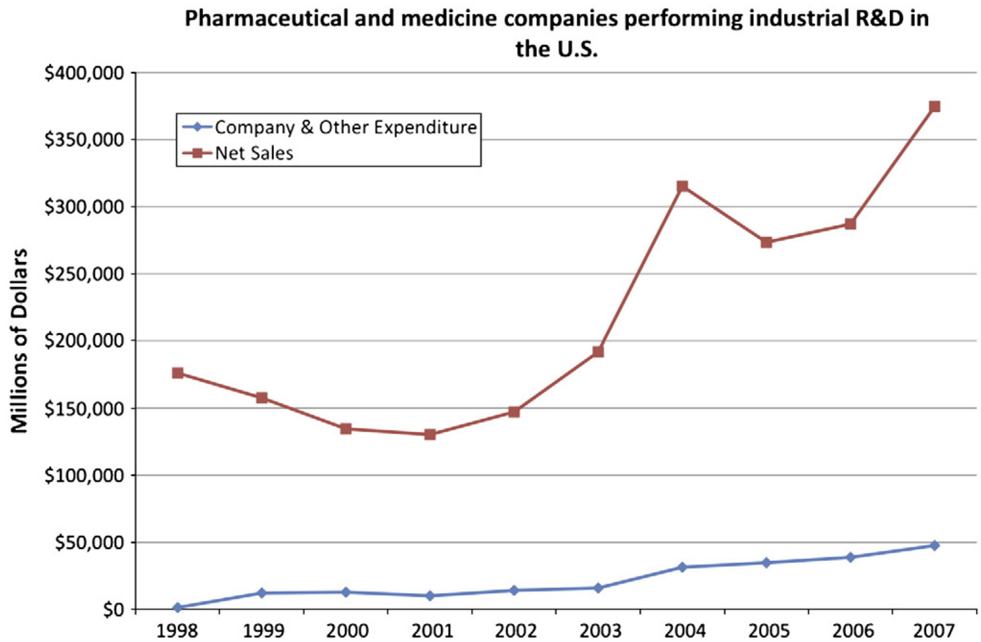

Fig. 5. Pharmaceutical and medical companies performing R&D in the U.S.
Source: National Science Foundation, Division of Science Resources Statistics (SRS).

behavior. Rent-seeking behavior is the pursuit of unearned profit, and any resources used for this are wasted, making it inefficient to limit the exchange of socially beneficial information. A second cost of patent trolling is that it increases transaction costs for users of information. Patent trolling creates barriers for innovators by distributing patent rights on one technology across various patent holders, making it significantly more difficult to detect potential infringed patents and increases the price of using information and hence blocks the creation of new technologies. The resources allocated to resolving the resulting legal conflicts are purely transaction costs, contributing nothing to net social welfare, and creating a double negative since it's money spent on reducing economic efficiency. As an example, one team of scientists wanted to develop rice genetically modified to produce vitamin A to improve the health of the world's poor. After they developed this 'golden rice', scientists found that depending on which country was to use it, the rice infringed on approximately 40 existing patents and would require negotiation with 12 to 20 separate entities (Kryder et al., 2000). With licensing arrangements too complex to negotiate, the researchers provided AstraZeneca, a private corporation, full commercial rights to the rice but retained non-commercial rights for national and international research and poor farmers in developing countries.

The second issue is the incentive structure. The current incentive structure encourages investment in new innovations by creating private property rights in the form of patents. By giving exclusive rights to organizations, patents create an economic market for ideas that have commercial potential and encourage organizations to invest monetary capital in the creation of information that may have otherwise not been developed (Kitch, 1977; Hellman, 2007). However, with the right to exclude others from potentially critical information for extended periods of time, patents inhibit further innovation and create dead-weight loss in the form of monopolies around innovations (Heller and Eisenberg, 1998a,b; Gallini and Scotchmer, 2002), making it more difficult to reach our desirable ends. An alternate incentive structure is required which provides the necessary incentives to produce the desired information, but leaves the information freely accessible to those who benefit most from it and those that can utilize it most efficiently to further knowledge.

The third issue is the allocation of scarce resources towards information production. In 1980, the Bayh–Dole Act was passed allowing publicly funded research to be patented and privatized, as opposed to forcing it into the public domain. It also gave individual governmental agencies authorization to patent and sell patents to large corporations. The act was passed in an attempt to spur commercialization of research done within universities and government laboratories. By granting private corporations exclusive rights on innovations from federally funded research, a situation is created where the public pays twice for innovations, once through taxes to support the federal research and again through monopoly prices on goods. The allocation of resources in a way that grants private corporations double income creates a net social loss (Eisenberg, 1996) and gives corporations, through the use of the market, the freedom to dictate society's goals.

An additional resource issue exists when pharmaceutical companies expend an enormous amount of research on 'me-too' drugs (Angell, 2004)—highly profitable drugs that other companies attempt to replicate and patent with no or very minor improvements to existing drugs. Such a replication of effort drains research resources. For example, in 2003, me-too drugs accounted for 44% of use and 63% of expenditure in Canada (Morgan et al., 2005). This occurs within other industries as well—currently, hundreds of models of digital cameras exist, with only minor differences between them. This reduces market efficiency since markets require perfect information, and the proliferation of products increases the costs of acquiring information and making intelligent decisions about what to buy. The duplication of any existing information wastes resources that could be better spent on developing new ideas and technologies that would increase well-being. Another tactic is to slightly modify a product as a means to re-patent it when an existing patent expires; this offers no additional value, but is a means of closing access to information for an additional period. Without the profit motive, research funds would not be wasted on such activities. Complete disclosure of discoveries and information would eliminate these drains in resources by providing peer groups and consumers the opportunity to evaluate products, making it monetarily inefficient for industries to dedicate resources to the replication of information.

4.2. Consumption Side

Patents create private property rights on innovations, allowing them to be bought and sold. Placing a price on information creates a rationing mechanism—only those willing or able to pay the price receive access to the information. Unless that information causes harm, additional use of the information creates no additional costs, and may even provide additional benefit if that information is enhanced. Because information is not a scarce resource in an economic sense, a rationing mechanism, as created by patents, is socially inefficient and may lead to the inability to meet society's desirable ends. In this section we use examples to show how economic markets can inefficiently allocate critical information after it has been produced.

NOAA recently reported that the greatest thinning of the ozone layer in history occurred in 2006 (NOAA, 2008). The 1987 Montreal Protocol on Substances That Deplete the Ozone Layer banned CFCs but allowed HCFCs as replacements since they offer a 95% improvement on CFCs in terms of ozone depletion. Unfortunately, with an increase in income in China and India, the demand for refrigerants in the two countries has resulted in an increase of HCFC consumption (Fig. 6), creating a net effect of more ozone depletion than prior to the ban (ESA, 2006; Bradsher, 2007). Although, alternatives to HCFCs that do not deplete the ozone layer exist, royalties from patents increase their price and hence deter use. This creates a situation in which it would be socially beneficial to pay China and India to use safer alternatives to HCFCs. Instead we charge them for the use, leading to potentially catastrophic outcomes.

Similar examples can be found within the pharmaceutical industry and the patenting of genetic material (Fig. 7). Under the Convention on Biological Diversity (CBD), countries have sovereign rights over genetic material within their boundaries, which includes samples of the avian influenza virus taken from people affected. In 2006, Indonesia began withholding samples of the virus from the World Health Organization (WHO) pending a reevaluation of the global mechanism for virus sharing. With this declaration, Indonesia protested the obligation of WHO members to share virus samples with no obligation on WHO to then equitably share the benefits (Khoon and De Wildt, 2008). The WHO system often developed patented vaccines from viral source material obtained in developing countries and targeted them at wealthy countries, making them too expensive and inaccessible to the Indonesian population and other developing countries that often have the highest need for vaccines. As an attempt to protect its population, Indonesia signed a memorandum of agreement with a private company, Baxter, to directly sell them samples of the virus in return for free access to the vaccine (McNeil, 2007). Although this may have solved Indonesia's access problems, it limited access to the vaccine to the rest of the developing world. Inaccessibility to the vaccines by a large pool of the poor population dramatically increases the likelihood of a pandemic and hence creates a social inefficiency.

In the coming decades, society will undergo an energy transition away from fossil fuels towards alternative energy sources. The challenge lies in determining which energy source has the greatest energy return on investment (EROI) and least impact on our environment. However, in an attempt to gain a competitive edge, companies producing these technologies patent and copyright all detailed information about the technology, making it difficult to do an accurate comparison. In a recent meta-analysis done on the EROI of operational wind turbines (Kubiszewski et al., 2010), an EROI ranging from below 1 to approximately 77 was found. Operational turbines provide the best opportunity to calculate actual EROI, as concrete data for input and output parameters is available, providing the ability to make accurate comparisons to other energy sources. However, this data is kept secret, making it inaccessible to perform analyses and for society to determine which energy source to transition to or even which source to invest funds in.

Other examples with similar dire results exist, including ones that are more hypothetical, such as inventing a clean, renewable, decentralized, and carbon free alternative to fossil fuels but patenting it and charging royalties so high that poorer countries continue to burn coal, allowing global climates to become unstable. Fig. 8 is a map of the proportional distribution of the 312 thousand patents granted in 2002 globally. While Fig. 9 shows the royalties and license fees received on grants or copyrights that same year. The United States received over $44 billion that year, making up approximately 53% of the global $83.8 billion paid for the use of ideas, technology, artistic work, and societal knowledge. Restricting access to existing information that protects or enhances public goods creates social costs when those restrictions serve no purpose within society. Most economists agree that including costs above market price generates social and resource allocation inefficiencies.

4.3. Alternative Incentive Structures

Because the market is unable to (1) properly allocate resources towards public goods that are most likely to be the desirable ends in today's world of climate change, fossil fuels, water scarcity, etc.; (2) increase production costs for restricting access to information, rent-seeking behavior, or transaction costs; and (3) decrease consumption benefits through price rationing that creates artificial scarcity, alternative

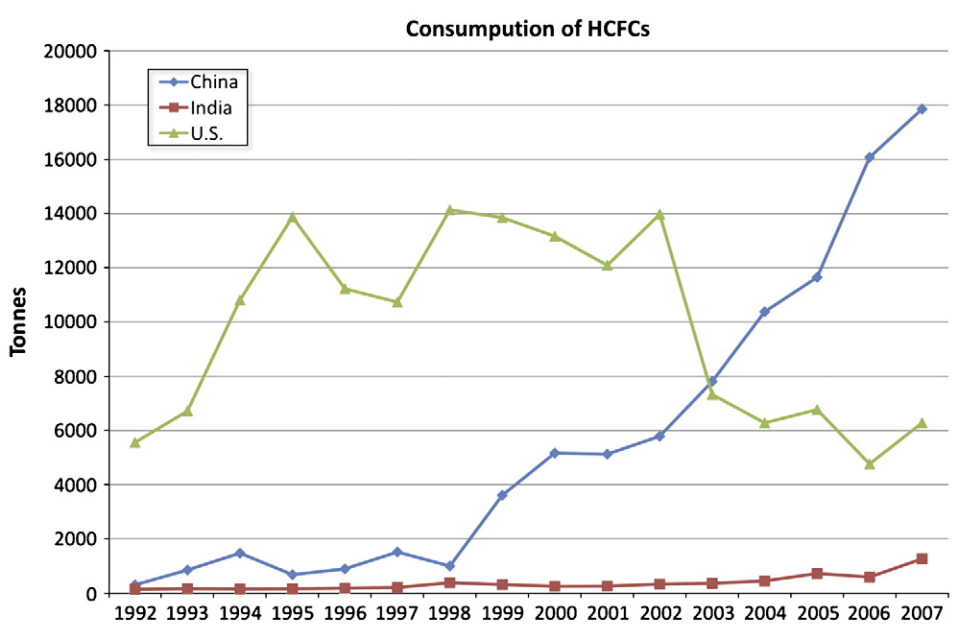

Fig. 6. Consumption of HCFCs in China, India, and the United States from 1992 until 2007. Source: UNEP.

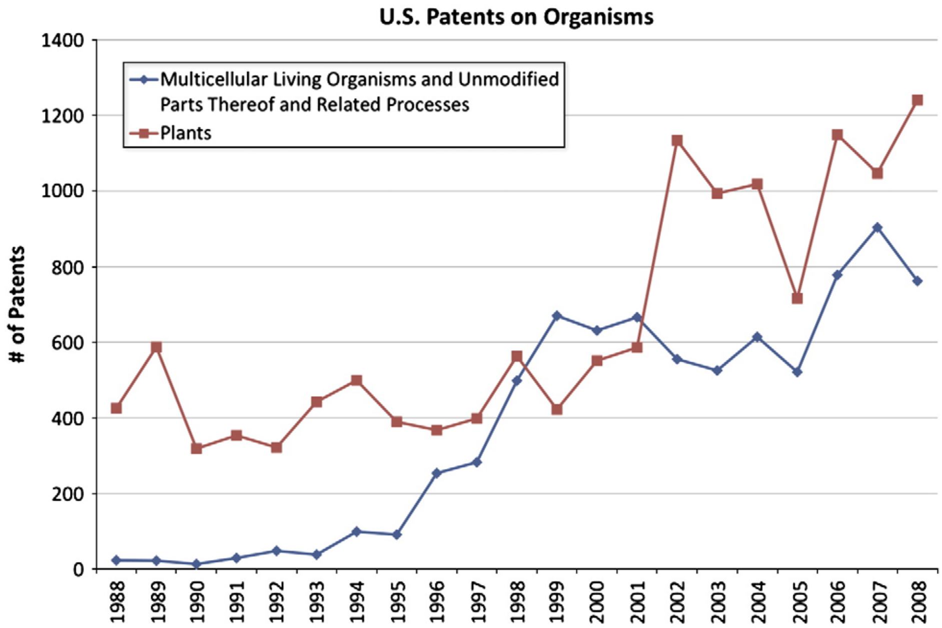

Fig. 7. Annual U.S. patents granted in the 'Multicellular Living Organisms and Unmodified Parts Thereof and Related Processes' (800) and 'Plants' (PLT) USPTO classes. Source: U.S. Patent and Trademark Office.

incentive and allocation mechanisms are required. Throughout history, various incentive schemes have been used to successfully encourage development of specific technologies or solutions to specific scientific problems. Here we review some of these systems and propose some new ones.

4.4. Prizes

One of the most popular alternative allocation methods has been rewarding innovations with monetary prizes and then releasing the information into the public domain. This includes France offering a prize for the development of the workable water turbine in the seventeenth century (Reynolds, 1983), a century long reward, around the same time, for the development of a method to calculate longitude while at sea (Sobel and Armstrong, 1995), or more recently, a prize for sending the first private astronaut into space (Schwartz, 2004). The use of monetary prizes as an incentive to develop specific information has certain advantages over the use of intellectual property rights. It allows society, and not just the market to decide on which innovations would be most beneficial. Because corporations would be rewarded monetarily through the prize, patents would no longer be necessary on the innovations, allowing the information to be released to the public domain and utilized by more researchers (Stiglitz, 1999a,b). However, this approach does fail to address the issue of firms competing for a prize instead of collaboratively working together during the production process, thus losing the gains to cooperation during the process.

4.5. Non-Monetary Incentives

Certain industries do not use monetary incentives as a reward structure. Open-source software has recently reemerged as a strong

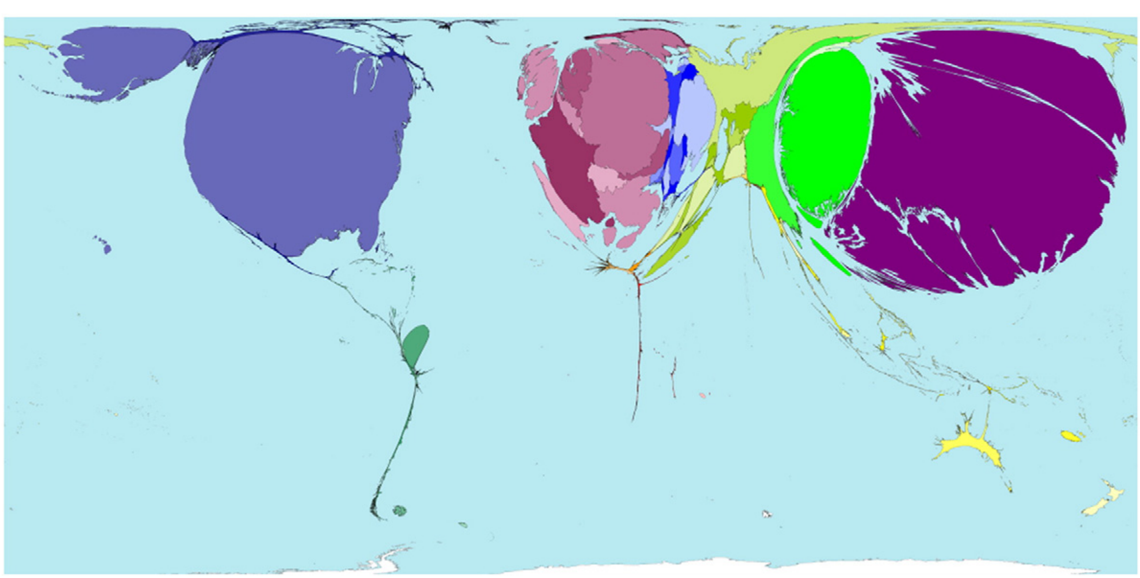

Fig. 8. This map presents a 2002 distribution of the 312 thousand patents granted that year, globally. The territory size indicates proportion of patents granted. Source: WorldMapper, Copyright 2006 SASI Group (University of Sheffield) and Mark Newman (University of Michigan).

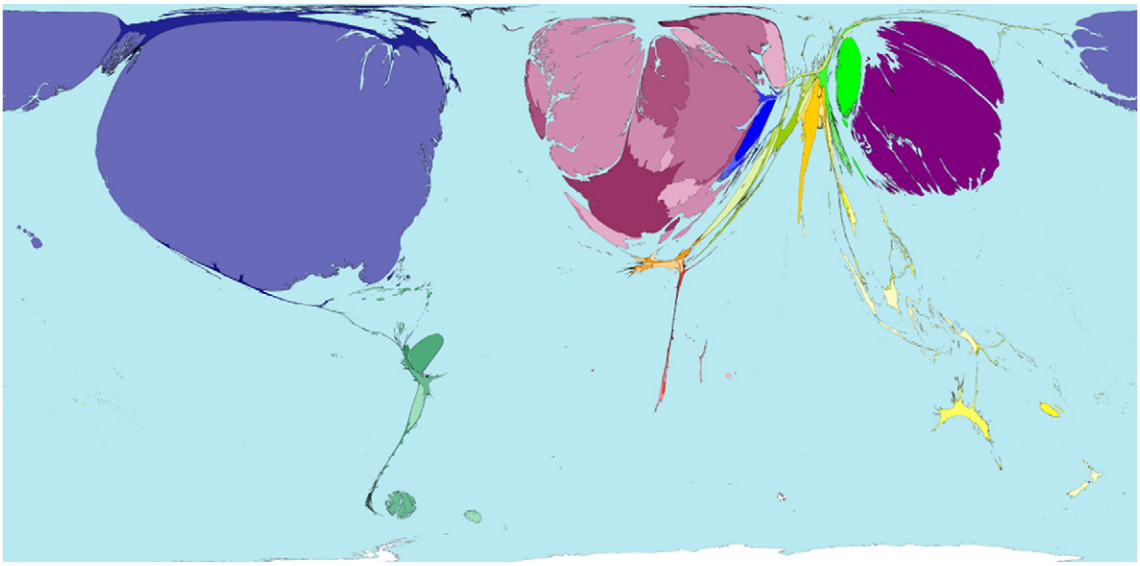

Fig. 9. This map presents a 2002 distribution of the $83.8 billion paid in royalties or licenses that year, globally. The territory size indicates earnings (in purchasing power parity). Source: WorldMapper, Copyright 2006 SASI Group (University of Sheffield) and Mark Newman (University of Michigan).

competitor to patented software and in certain circumstances significantly exceeding its quality (e.g. Firefox vs. Internet Explorer) (Bitzer et al., 2007). Within this open-source community and many academic fields, a type of incentive structure exists based on an individual's reputation amongst his colleagues for contributions to the field. This system rewards based on how quickly discoveries are made and how quickly they are published within the community (Dasgupta and David, 1994).

In academia, mathematical theorems cannot be patented, and yet many mathematicians continue to work on their development. The extent of the reward given to an academic working within this system is determined by the community as a whole. The community assesses the quality of the discovery, after its publication, on the criteria of how much it benefits that community and how much it furthers that community's knowledge. The rewards may be monetary in the form of a promotion but commonly consist of such things as honorific awards, positions at more prestigious universities, tenure, large citation numbers, colleagues' esteem, and overall status. The size of the reward is dependent on how much the discovery benefits the community, or in other words, how much it advances the community's efforts towards a single goal or vision. This communal vision is established not by the market but by the community as to what the most desirable ends are.

Besides advancing knowledge in the entire community, the act of publication also serves two other purposes. First, it ensures that the discovery does not remain within the confines of a group which may not have the resources or ability to utilize that discovery to its fullest. Second, the ability for peers to evaluate the discovery, the opportunity for errors is significantly minimized (Dasgupta and David, 1994). However, once a discovery is completely disclosed to the community through publication, it becomes simple for others to copy portions of the published work and claim to have also independently done the research. Consequently, academia does not reward second place discoveries, encouraging academics to collaborate instead of competing to discover and publish first.

The passing of the Bayh–Dole Act of 1980, provided universities an impetus towards commercial innovations, creating an increasing trend in patenting (Fig. 2) as a means of additional monetary rewards (Mowery et al., 2001; Sampat, 2006). Subsequent policies have strengthened privatization of research results by giving priority to anyone involved in a project that wants to patent information over the objections of anyone who believes the discovery should be placed in the public domain (Eisenberg, 1996). Moving away from monetary incentive structures and towards those dependent on peer opinion would provide strong impetus to release all information into the public domain.

4.6. Capping Salaries

Historically, inventors worked independently in either the pursuit of profit (e.g. Thomas Edison) or to contribute to the public good (e.g. Nikola Tesla). Today, the majority of scientists work within the private or public sectors, with defined salaries. The rights to any patents they procure are assigned to the organizations that they work for, eliminating much of the incentives for the individual scientists to research one type of information over another. By capping salaries amongst the different sectors, scientists would have no incentive to work for corporations such as Bristol Meyers Squibb over the National Institute of Health. A natural cap could be forced by taking away the right of major corporations to patent drugs that are beneficial to society. Through their choice of organizations, scientists would have the discretion of deciding on how the results of their research were to be utilized. By offering competitive salaries, the government would have the opportunity to promote the type of research most beneficial to society.

4.7. Research Consortium

A global research consortium should determine appropriate technologies for alternative energy, agroecology, green chemistry, industrial ecology, and so on in collaboration with those who would use them. These new technologies could be "copylefted" (as opposed to copyrighted), meaning that they are freely available for anyone to use as long as derivative products are available on the same terms (Bollier, 2003). This would allow the consortium to determine that the research priority included finding an alternative, clean sources of energy, protecting the ecosystem services, managing fresh water efficiently, or feeding the world's hungry. This institution would consider the global well-being of the population instead of purely economic demand.

4.8. Publicly Funded Research

Potential also exists to move away from the market in funding certain types of research. In the 1950s and 1960s the government funded much more than half of all research and development in the U.S., but by 2006, it funded only 28% (Fig. 10). By increasing the proportion of publicly funded research and placing all information obtained through publicly funded

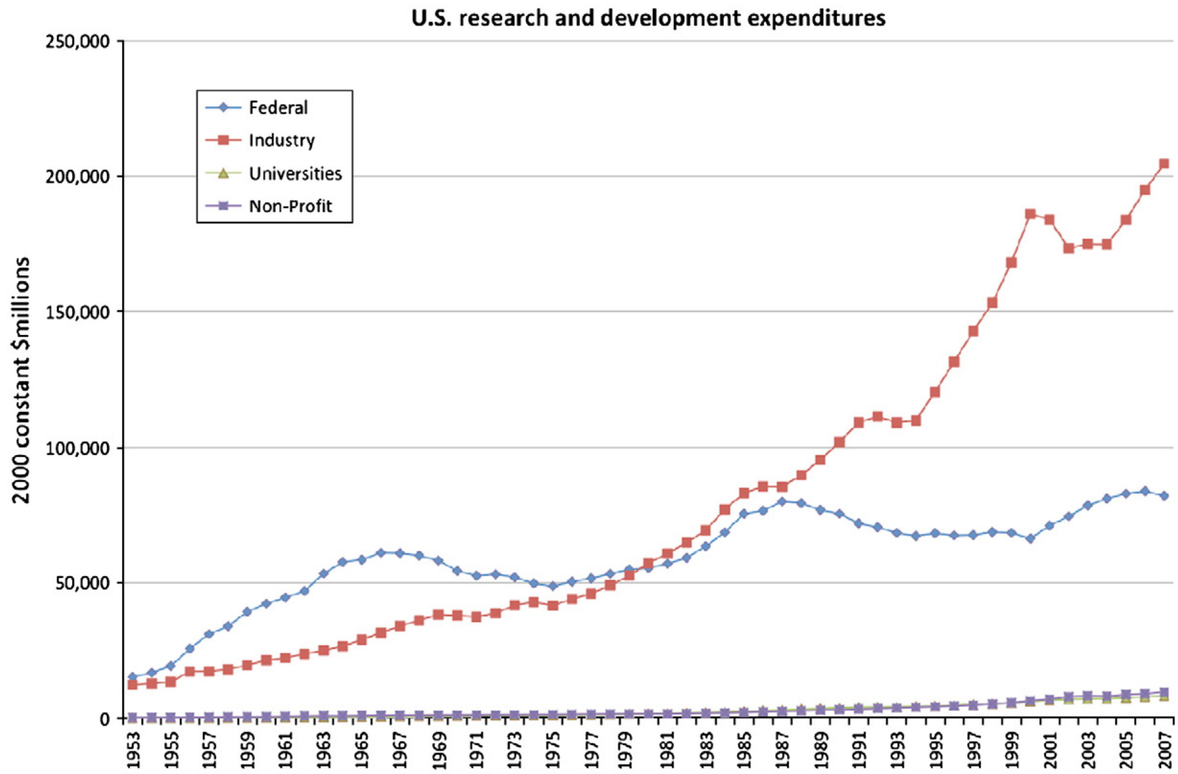

Fig. 10. Sources of funding for research and development in the US.
Source: National Science Foundation, Division of Science Resources Statistics (SRS).

research into the public domain, monopoly pricing on this technology would no longer be an option, creating both open information and competition for further advancements, two critical aspects to the proper functioning of the market. It would also eliminate 'me-too' research, using resources more efficiently. Taxpayers would still be required to fund further advancements in research through the price of goods, however, that price would be set by a market instead of by a single corporation. Patents also create a strong incentive to research information that is potentially commercializable instead of basic research (Salter and Martin, 2001) or applied research that provides and protects public goods, which has historically been an important resource for other researchers in both the public and private sectors (Scotchmer, 1991). Placing information into the public domain would take the focus away from commercializable items and refocus research on areas most necessary for solving society's problems (Stiglitz, 1999a,b; Stiglitz, 2002; Stern et al., 2006).

Large governmental grants can also be used to bring together top researchers in specific fields from multiple corporations, universities, and governmental agencies to work together toward common goals. Besides placing the smartest people on a certain topic together to exchange ideas, it would also create collaboration between different institutions and avoid the competition that usually occurs. The information produced would be released into the public domain, allowing the entire world, including developing countries, to benefit. Such systems were used to spur both the Green Revolution and to get humans to the moon, creating remarkable scientific advancements in short periods of times, and in one case deterring a mass famine.

Additional public funding for R&D could be made available through the taxing of certain excludable goods within specific industries. As an example, the computer industry has been having significant difficulties in stopping the pirating of software. Software, due to its nature, should not be an excludable good because after it is developed, the creation of an additional copy has insignificant marginal costs associated with it. This creates a significant social inefficiency. If a system were established in which the hardware was taxed and the revenues used to fund software development that was provided freely to the users, this would eliminate the social inefficiency. Similar taxes can be placed on the energy industry. Technologies based on fossil fuels and use of the fuels themselves could be taxed (or permits auctioned) and that money could be directed towards the development of alternative energy technologies. Such a tax would have multiple advantages, including the reduction of greenhouse gas emissions (Barnes et al., 2008).

5. Conclusion

Goods and services that improve with use, such as information, require alternative incentive structures. Although market-based allocation systems have the advantage of providing incentives to create new information, they fail to correctly determine what information needs to be produced to reach society's desired ends or how that information should be allocated once it's produced. With consumptive goods no longer necessary to improve well-being, but information that improves and protects public goods being required, a different allocation system is required for both the production and consumption side of information. Since information is the basis of economic production, common ownership of information would significantly increase information transfer and produce a greater rate of innovation. It will also provide a means of allocating information towards the desirable ends of society and the common good by allowing a larger number of scientists and researches access to the information.

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