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Financing environmental improvements: A literature review of the constraints on financing environmental innovation

By
Daniel K.N. Johnson and Kristina M. Lybecker

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Department of Economics and Business
Colorado College
Colorado Springs, Colorado 80903-3298
www.coloradocollege.edu/dept/EC

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Daniel K.N. Johnson
Kristina M. Lybecker

Department of Economics and Business
Colorado College
14 E. Cache la Poudre Street
Colorado Springs, CO 80903

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Daniel K.N. Johnson is the Gerald L. Schlessman Professor of Economics and Director of the Innovative Minds Program at Colorado College, 14 East Cache La Poudre, Colorado Springs, CO 80903, tel 719-389-6654, djohnson@ColoradoCollege.edu.

Kristina M. Lybecker is Assistant Professor of Economics at Colorado College, 14 East Cache La Poudre, Colorado Springs, CO 80903, tel 719-389-6445, kristina.lybecker@ColoradoCollege.edu.

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Executive Summary

In an effort to explore the potential for financing environmental innovation, this paper examines different forms of financing and attempts to evaluate their effectiveness. The study considers both public and private forms of funding as well as providing policy suggestions for the support of appropriate financing for eco-innovation.

Key Findings:

- The literature on the financing of innovation is very limited, and a virtually non-existent literature on the funding of eco-innovation in particular.

- R&D spending in the energy sector is relatively quite small, when compared to other industries and sectors. In addition, since fossil fuels receive close to one-quarter of the federal funding it is perhaps not surprising that there is a dearth of research on funding for eco-innovation.

- Innovation is inherently risky and uncertain. Moreover, if we are unsure about the rate of innovation, then we have difficulty predicting the pattern of global climate change, which makes it difficult to substantiate the reasons for further research funding.

- Public funding occupies a significant and important position in innovation financing. One essential role of government is the funding of basic research, especially technologies that are not in and of themselves commercially viable, but may serve as a springboard for subsequent innovation. Further, of one hundred lines of inquiry only one might merit commercialization by venture capital funding.

- Environmental innovation is complicated by both environmental externalities as well as the public good nature of the technology. R&D subsidies address the public good characteristic, but fail to account for the environmental externality, so do not address adoption challenges. Subsidies, either R&D or production subsidies, are an easy target for interest groups, creating a political challenge. As a result, subsidies frequently take less transparent forms such as price controls that reduce prices below full cost.

- It is clear that energy and agriculture are two of the most heavily subsidized economic sectors, and both impact directly on the ability of eco-innovation to draw resources and to draw consumers. Global energy subsidies are close to $300 billion per year and the majority of these serve to lower consumer prices in non-OECD nations. Alternatively, in OECD countries, most subsidies go to production in the form of direct payments or as R&D support. Roughly eleven percent of that total supports the distribution of low-carbon energy.

- While taxing carbon-intensive fuels may be a more economically efficient mechanism, it is probably politically unfeasible. Moreover, economists cannot even cleanly recommend the elimination of subsidies for fossil fuels due to the complexity of the system. For example, encouraging the use of oil products such as kerosene can curb deforestation.

- Most innovation is still funded by private sources, whether internal to the firm itself (e.g. via retained earnings) or through third-party funding sources (e.g. bank loans, venture capital). Moreover, corporate interest in eco-innovation is largely market-driven, so policymakers would do well to ensure that the incentives and abilities to early profits are appropriate and preserved.

- It is important to note that there is some evidence that appropriate funding may differ based on the stage of the innovation's life cycle. Current case studies appear to favor technology push factors early in the product cycle, versus market opportunities later in the cycle.

- Finally, empirical studies frequently identify the lack of access to credit as a significant barrier to adoption and technological diffusion. For environmental innovators, the challenge is not only attracting sufficient funding, but ensuring that the associated incentives are appropriate to the lifecycle stage.

This paper concludes that the challenge to policymakers is one of balance: encouraging financing and removing obstacles to the process while still allowing the wisdom of the market to function and the powers of the invisible hand to best guide investments. While the importance of eco-innovation is increasingly evident, the mechanisms for funding these technologies remain largely unexplored. A rich set of questions remain to be answered, questions that will help reveal the most efficient and effective means of financing environmental innovation.

Financing environmental improvements:
A literature review of the constraints on financing environmental innovation

This is the third paper in a series of three literature reviews designed to summarize the state of academic knowledge surrounding the economics of environmental innovation. The previous papers in this series consider the challenges of innovation and of dissemination or diffusion of that technology. This paper examines the history and effectiveness of different forms of financing, along with policy suggestions for the support of appropriate financing for eco-innovation.

Introduction

"A vision without resources is a hallucination."
-- A reputed Pentagon phrase quoted by Friedman (2006).

There is a limited literature on the financing of innovation, and a virtually non-existent literature on the funding of eco-innovation in particular. This review will point out what is known, along with suggestions for study to fill in obvious holes in our knowledge. It will also use what is known about financing more broadly, drawing implications for eco-innovation purposes.

Friedman (2006) calculates that the energy sector (including oil, coal and gas) receives about $3 billion in federal funding for research and development, with another $5 billion in private sector and venture funds. If accurate, that amounts to roughly 0.8% of revenues in the energy sector. In contrast, Friedman asserts, manufacturing sectors average 6-8% of revenues. At one-tenth of the relative research intensity, surely our energy sector is under-investing in innovation?

Immelt (as quoted in Friedman, 2006) states that the difference between energy and health sector R&D spending over the last two decades has been about $50 billion. Moreover, fossil fuels receive roughly one-quarter of the federal funding, further limiting the impact of research funding on alternative energy sources. In short, one possible reason for a dearth of research on research funding for eco-innovation is that it simply does not appear important in size to the average economist or think tank.

In their authoritative work, Jaffe et al. (2001) assert that uncertainty about the future rate and direction of technological change is often the largest single source of differences among predictions in global climate change modeling. That poses a set of interrelated problems: if we are unsure about the rate of innovation, then we have difficulty predicting the pattern of global climate change, which makes it difficult to substantiate the reasons for further research funding (which itself leads only uncertainly to innovation, since many financed research paths are scientific dead-ends or are commercially unviable).

In response to findings of this nature, Friedman (2006) argues, as do many voices before him, that one role of government should be to fund basic research, since of one hundred lines of inquiry only one might merit commercialization by venture capital funding. However, it is tough to justify those expenditures to an electorate unsure of the impact on global problems or even the scope of the problems themselves.

Given the uncertainty surrounding innovation and its financing, effective guidelines are especially valuable. Morgan (2007) presents the following fairly exhaustive list of criteria for policies aimed at mitigating climate change, a list which is also applicable to the support of eco-innovation. Effective policy must be:

- well-targeted, so that subsidies go only to those who are meant and deserve to receive them.
- efficient, so that subsidies do not undermine incentives for suppliers or consumers to provide or use a service efficiently.
- soundly based, justified by a thorough analysis of the associated costs and benefits.
- practical, in the sense that the amount of subsidy is affordable and that it is possible to administer the subsidy in a low-cost way
- transparent, so that everyone can see the amount of subsidy and who receives it.
- limited in time, so that consumers and producers do not get "hooked" on them and the cost does not spiral out of control.

Innovation is inherently risky and uncertain. This presents particular difficulties to all parties involved: innovators, funding agencies, regulators and policymakers. This review aims to provide some direction for all agents, exploring the existing body of work on financing for innovation and drawing out the lessons particularly relevant for environmental innovation. The paper proceeds with an outline of some possible forms of financing in the following section, both public and private. We then offer some suggestions for research that might illumine the discipline in this area. Finally, we conclude with some considerations for policymakers.

Types of financing

There are myriad types of financing currently available, limited only by the creativity of the private agents and public officials interested in supporting innovation. We offer a review of some, but encourage the reader to think of alternatives, rather than being limited by current offerings. Sadly, the economics literature does not tend to analyze along this public-versus-private typology (see Jaffe and Lerner, 2001), so the comparison clearly calls for further research.

Morgan (2007) describes the existing approaches to subsidies for clean energy. These are systematically presented in Table 1 below.

a) Public funding

Public funding occupies a significant and important position in innovation financing. The National Science Foundation reports that "in 1998 about 30% of U.S. research was funded by the federal government" (Gallini and Scotchmer, 2001). To that point, Jaffe and Lerner (2001) report that in 1993, the U.S. federal government funded about eighteen percent of all R&D in industrialized countries. Moreover, Morgan (2007) reports, citing the Stern Review on climate change, that government support to low-carbon energy sources currently approximates \$33 billion globally: \$10 billion on deploying renewable, close to \$16 billion to support existing nuclear power activities, and \$6.4 billion for biofuels. Obviously, funding may take a variety of forms, including the multiple varieties reviewed here.

Table 1: Existing Approaches to Subsidizing Clean Energy (Morgan 2007)

Incentive	*Example*
Fiscal incentives	Reduced taxes on biofuels; investment tax credits
Capital grants	For demonstration projects such as the clean coal programme in the US; photovoltaic (PV) rooftop programmes in the US, Germany and Japan; marine renewables in the UK and Portugal.
Feed-in tariffs	Fixed price support mechanism, usually combined with a regulatory incentive to purchase low-carbon power output, e.g., wind and PV in Germany; biofuels and wind in Austria; wind and solar schemes in Spain; wind in Netherlands.
Quota-based schemes	Renewable Portfolio Standards in 23 US states; vehicle fleet efficiency standards in California.
Tradable quotas	Renewables Obligation and Renewable Transport Fuels Obligation in the UK.
Tenders for tranches of output	Uplifted output prices paid for a general levy on electricity tariffs, e.g., the former UK Non-Fossil Fuel Obligation
Grants to infrastructure	Covering the cost of connecting new technologies to the electricity network.
Public utility procurement	Historically the approach of public electricity monopolies for the purchase of nuclear power in OECD countries. Currently used by China. Often combined with regulatory agreements to ensure cost recovery, soft loans and government assumption of nuclear waste liabilities.
Government procurement	Demonstration projects for public buildings; use of fuel cells and solar technologies by defence and aerospace industries; hydrogen fuel cell buses and taxis in cities; energy efficiency in buildings.

Source: Stern (2006).

i. Subsidies

Hall and van Reenen (1996) review the literature on the effectiveness of public subsidies for R&D and their conclusions are not enthusiastic. In the short-run, subsidies generate far less than a proportional financial value of private research, and only in the long-run does a dollar of subsidy create a dollar of private research. Popp (2006) notes that R&D subsidies, as opposed to production subsidies, address the public good nature of this technology, but fail to account for the environmental externality, so do not address adoption challenges. Clearly the use of subsidies must be carefully calibrated in order to most effectively fund innovative projects and research.

This theme is echoed in the work of Morgan (2007). He concludes that "a subsidy, by affecting cost and/or price, always causes a shift in economic resource allocation. Energy subsidies deliberately distort price signals and, therefore, investment in infrastructure to supply different fuels and in the capital stock that transform or consume energy." Morgan structures the different forms of public subsidies that energy might take in a helpful table (reproduced below). He considers both direct and indirect forms of support, noting the means through which the subsidy works, either price or cost. He finds that the majority of mechanisms operate through lowering costs of production rather than prices.

Table 2: Main Types of Energy Subsidy
(Morgan 2007)

Government intervention	Example	How the subsidy usually works: Lowers cost of production	Raises price to producer	Lowers price to consumer
Direct financial transfer	Grants to producers	v		
	Grants to consumers			v
	Low-interest or preferential loans	v		
Preferential tax treatment	Rebates or exemptions on royalties, sales taxes, producer levies and tariffs	v		
	Tax credit	v		v
	Accelerated depreciation allowances on energy supply equipment	v		
Trade restrictions	Quotas, technical restrictions and trade embargoes		v	
Energy-related services provided directly by government at less than full cost	Direct investment in energy infrastructure	v		
	Public research and development	v		
	Liability insurance and facility decommissioning costs	v		
Regulation of the energy sector	Demand guarantees and mandated deployment rates	v	v	
	Price controls		v	v
	Market-access restrictions		v	

Source: Adapted from UNEP/IEA (2002).

Morgan (2007) further describes the political challenges of subsidies in terms of transparency. Given that on-budget subsidies are an easy target for interest groups, subsidies frequently take less transparent forms such as price controls that reduce prices below full cost. "Government intervention, which may involve the use of subsidy, is intended to remedy market failures, such as pollution and global warming, either by addressing their causes or by trying to replicate the outcome of an efficient market that maximizes social welfare." While price controls comprise a less-easily-targeted form of support, this may come at the expense of efficiency considerations.

In contrast, Copenhagen (2009) sees a danger in subsidies, namely that they become distortions, compensating for performance. In their words,

> "Grant subsidies from developed countries to encourage developing countries' access to specific IPR-protected carbon abatement technologies may actually distort the market and result in the acquisition of not very cost effective carbon abatement technology. Instead, support should compensate low-income developing countries for the overall economic burden of carbon abatement while preserving the countries' incentive to minimize the costs of that abatement." (Copenhagen, 2009)

The Copenhagen (2009) study is a rare example of work that specifically examines the financing of environmental innovation in the context of developing countries.

ii. Tax credits

To our knowledge, there is no literature evaluating the impact of tax credits on environmental innovation, or even of innovation in general. There is one assertion that we identified, namely that tax credits are not a good idea in less developed nations due to the presence of large informal sector activity which would not value tax credits (Aubert, 2004).

iii. Direct financing

In like manner, there is a dearth of literature on the effects of direct public funding of research toward environmentally related ends. Work by Jaffe et al. (1997) in the U.S. has found that federally funded research on average leads to patents that are more general in technology, and more geographically dispersed in usage than other privately-funded research activity. Popp(2002) finds that government energy research and development served as a substitute for private energy R&D during the 1970s, but as a complement to private energy R&D afterwards. One explanation is the changing nature of energy R&D. During the 1970s, much government R&D funding went to applied projects such as the effort to produce synthetic fuels. Beginning with the Regan administration, government R&D shifted towards a focus on more basic applications.

Jaffe and Lerner (2001) analyze patents issuing from U.S. federal labs, and compare them to patents from research universities. They find that directly financed research at federal labs has improved since policy changes of the 1980s, reaching the same number of patents per dollar of R&D as universities show. At the same time, the academic quality of their research has been increasing as universities have not. In short, their results are consistent with the economics literature on the reasons to privatize government functions.

iv. Cost-sharing and joint ventures

We found no literature evaluating the effectiveness of private-public cost-sharing as a funding technique for innovation, or for eco-innovation more specifically. Copenhagen (2009) notes that Brazil and China have recently advocated for a “multilateral technology acquisition fund”, suggesting it should be financed by developed nations. The fund would assist developing countries in acquiring carbon abatement technology at low cost.

In addition, Aubert (2004) describes Fundacion Chile, originally a joint venture between the Chilean government and the US firm ITT, as one of the most successful attempts in Latin America to establish a national agency for new technology. The organization has been quite successful in incubating new ventures through entrepreneurship and new technologies. Successful factors included

> “an entrepreneurial, highly paid and highly professional management team (which takes years to establish); arms-lengths relationships with the government; operates as a business, not as a public sector organization; private shareholders which do

> not expect an immediate return and tolerate risks ('oligarchs with a strategic agenda')." (Aubert, 2004)

Laffont and Tirole (1996a) showed a theoretical model to reorganize tradable permits markets with an attached futures market to encourage eco-innovation. With application to existing emissions markets, this might encourage greater eco-innovation if the pricing structure were set to share the costs with the administering agency.

v. Subsidies on substitute activities

It is clear that energy and agriculture are two of the most heavily subsidized economic sectors, and both impact directly on the ability of eco-innovation to draw resources and to draw consumers. Morgan (2007) asserts that worldwide energy subsidies are close to $300 billion per year worldwide (net of taxes), according to International Energy Agency data. Most of those subsidies serve to lower consumer prices in non-OECD countries, while in OECD countries most subsidies go to production in the form of direct payments or as R&D support. Roughly eleven percent of that total supports the distribution of low-carbon energy.

Unfortunately, the solution is not usually as simple as the removal of a subsidy on alternative activities. Morgan (2007) correctly points out that encouraging the use of oil products such as kerosene can curb deforestation in developing countries as poor rural and peri-urban households switch from firewood. He points out that while taxing carbon-intensive fuels may be a more economically efficient mechanism, it is probably politically unfeasible. He further suggests that governments may introduce compensation to support the real incomes of those who stand to lose, giving such targeted social groups time to adapt.

vi. Prizes

There is the potential for the use of prizes as an incentive for eco-innovation, to parallel the work of non-profit organizations which already use this tool in other venues (e.g. Bill and Melinda Gates Foundation for public health). Mandel (2005) suggests a prize system that might work alongside the patent system, using the structure already developed in the U.S. for atomic energy innovations (see the first paper in this series).

In a similar vein, Gallini and Scotchmer (2001) describe fixed-price contracts, a form of procurement frequently used in government-sponsored research, as operating much like prizes. Funding is provided in advance for proposed projects and costs are then paid as they accrue, whether or not the final product is delivered. Given that future grants are contingent upon earlier success, moral hazard problems are avoided. They note that fixed-price contracts are distinct from prizes in that researchers must convince the sponsor of the value of their output in advance. Specifically, they observe

> "If the investment's prospective value is known to the sponsor (or defined by the sponsor, as in the case of military wares), the sponsor can screen projects himself. A prize system then seems superior to IP. It avoids deadweight loss, and can be as good as IP at inciting effort." (Gallini and Scotchmer, 2001)

Newell and Wilson (2005) analyze prizes as a complement to research grants and contracts for the development of climate change mitigation technologies. The historical use of prizes as a successful inducement mechanism suggests a positive role for prizes in spurring climate change technology development. At the same time, the study finds that careful design is crucial to the use of prizes. The advantages and disadvantages of both types of mechanism are described in the table below.

Table 3: Comparison of Alternative Technology Policy Instruments (Newell & Wilson, 2005)

	Prizes	Contracts & Grants
Pros	• Prizes solve information problems by devolving risk onto researchers. • Prizes reward outputs. • They require less of a governmental investment than do direct contracts • Prizes leverage considerable non-financial incentives. • They encourage small, innovative players to participate by lowering barriers to entry.	• Contracts and grants avoid duplicative research. • In case of basic research, mutually aligned incentives reduce informational asymmetries. • Modifications (e.g., use of a proposal process) can reduce principal-agent problems. • Contracts and grants are able to encourage high-cost research.
Cons	• Prizes can lead to excessive duplication of effort. • They are less suited to high-cost projects where researchers cannot bear all risks. • Up-front liquidity constraints of prizes could lower participation.	• Participants are susceptible to shirking because of information asymmetry problems. • They are high non-financial barriers to entry. • Contracts and grants are less appropriate for applied technology research.

Given that most developed nations have a well-established tradition and system of soliciting private economic activity to fulfill government contracts, perhaps this is a suitable starting place for the procurement of eco-innovation. The challenge may be in convincing public authorities to support funding for pure research in this manner, and in developing appropriate contract goals and/or progress benchmarks.

b) Private funding

Most innovation is still funded by private sources, whether internal to the firm itself (e.g. via retained earnings) or through third-party funding sources (e.g. bank loans, venture capital). Unfortunately, the economics literature is extremely limited in evaluating the relative effectiveness of these funding avenues. This section briefly touches on corporate retained earnings and venture capital.

i. Corporate retained earnings

The importance of corporate research simply cannot be stressed enough. Friedman (2006) points out that the very deep pockets of research funds are in corporations, not in government agencies or in third party sources like venture capital. Microsoft alone had a research budget of $6 billion in 2007, more than all of the venture capital going to clean energy tech that year, and roughly triple the U.S. federal government's investments in energy efficiency and renewable energy R&D.

Given that corporations are such a significant source of research funding, it is essential to understand what motivates them. The reasons for corporate interest in eco-innovation are largely market-driven, so policymakers would do well to ensure that the incentives and abilities to earn profits are set appropriately (see the first paper in this series). While some R&D is undoubtedly done to "greenwash" or convince consumers of dubious environmental merits, the vast bulk is clearly done in recognition of either immediate profits from sales (i.e. lower costs or higher revenues) or future profits, frequently recognized in stock market valuation.

In the context of stock market valuation, there has been some work done on the impact that patents have on this calculation, but none specific to eco-innovation. For example, Cockburn and Griliches (1987) estimate the value of patents of 772 firms over the period 1973-1980, as reflected by the stock market. The study utilizes information from an industrial survey on the subjective value and appropriability of the underlying innovations. They find an average valuation of $500,000 per patent granted, but double that amount in industries where patent protection is stronger, that is, the appropriability of rights is greater. There is clearly value to future work that might extend these results, perhaps comparing patents in different sectors to evaluate their relative impacts on stock market valuation.

ii. Venture capital and angel funding

Kortum and Lerner (2000) perform a very careful analysis of the impact of venture capital financing on patenting activity in the U.S. and find that its presence is strongly positively associated with higher patent activity. In particular, they find that while it averaged only three percent of U.S. R&D between 1983 and 1992, it is associated with eight percent of industrial innovations over the same period.

The role of innovation life cycle

There is some evidence that appropriate funding may differ based on the stage of the innovation's life cycle. Bernauer et al. (2006) report that case studies appear to favor technology push factors early in the product cycle, versus market opportunities later in the cycle (Pavitt, 1984; Mowery and Rosenberg, 1979; Freeman, 1994; Jaenicke et al., 2000). When supply side forces are more important, namely early in the innovation's development, more direct involvement may be advisable, via direct funding or prize offerings. Later, as the innovation matures, demand side forces become more important, so encouragement of market forces via strong property rights and freely flowing information to stock market valuations and R&D tax credits to corporations may all work well. Of course, a potential challenge of environmental innovation is that both supply and demand forces may be relatively weak (Rennings, 1998).

Blackman (1999) notes that empirical studies frequently identify the lack of access to credit as a significant barrier to adoption and technological diffusion. All of the problems chronic to imperfect credit markets, such as the diversion of loans by borrowers to non-targeted activities and low repayment rates, challenge the ability of any credit market to exist for the funding of an inherently risky activity such as R&D or early-stage product adoption. Later in the innovation's life cycle, those problems may be less pronounced, as traditional lenders are more willing to provide funding for adoption and sale of established, mature technologies. Thus, it appears that innovators are challenged by not only attracting sufficient funding, but ensuring that the associated incentives are appropriate to the lifecycle stage.

Strategies for effective financing

Unfortunately, the economics literature has not focused on this issue in the past, so has little insight to offer on the relative merits of public versus private sources of funding for innovation. Within the scope of public financing, there is an infinite range of policies possible, each of which must be considered for the particular case at hand and the specifics of environmental innovations. Strikingly, economics cannot even cleanly recommend the elimination of subsidies for alternative activities, due to the complexity of the system in which we operate. The lack of work in this area points to an important avenue for future studies, though the associated difficulties and complexities of the system are expected to be significant and likely a reason for the existing dearth of studies.

Conclusions and policy implications

The three papers in this series have examined the existing body of work by economists on the challenges to environmental innovation: its development, dissemination and financing. Each element of this process is characterized by important uncertainties and significant risks. Accordingly, the transfer of environmental technologies, especially to developing nations is fraught with difficulties. Beyond the market forces and market failures at play, political and cultural forces intervene, further complicating the process.

Ultimately, this is a field of tremendous future important in which a significant number of questions remain to be answered. As before, the challenge to policymakers is one of balance: encouraging financing and removing obstacles to the process while still allowing the wisdom of the market to function and the powers of the invisible hand to best guide investments. This paper, more than the other two, reveals that an immense number of inquiries remains to be explored and our understanding is still in a nascent form. The rewards to this exploration are sizeable and the information essential to the future of environmental innovation.

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