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Literature Review of Emissions Control and Research and Development Externalities

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1. Introduction

As concern over climate change garners attention the question of whether it is happening gives way to what policymakers should do about it. The question of policy is an economic one. This research is necessary because climate change, left unchecked, threatens to permanently change our environment.

In Economic terms, CO_2 emissions would be described as an externality. The industries that produce the pollutant do not pay for the damages they inflict on the environment. Economists have deliberated on such externalities before. In a classic experiment, Plott argued that policy measures to internalize these externalities were necessary. That is, policies that include the cost of pollution in the economic decisions made by firms and consumers should be enacted. His reasoning, and experimental results, suggested that mere concern over the welfare of others is not sufficient to protect society from environmental damages (1983).

Plott, however, did not consider a further complication of environmental economics. A politically attractive solution to climate change is to support research and development (R&D) as an answer to climate change. The studies I consider here will consider this question in conjunction with methods of internalizing climate change externalities.

2. The Economics of Emissions Control

Previous literature reviews exist for the economics of emissions control and so this section will be a summary discussion of them. The focus of this paper is the relationship between emissions control measures and emissions R&D. For a more extended discussion of environmental experimental economics see Noussair and Soest (2014), and Friesen and Gangadharan (2013). Emissions control can be achieved through either a carbon tax or a cap-and-trade approach. There is some dispute over which is socially preferable and how to implement either. The trade-offs are that cap-and-trade generally requires less action on the part of the government and allows for control over the quantity of emissions, while a carbon tax is the more price stable alternative (Congressional Budget Office, 2008).

Because of the relative price stability of a carbon tax the Congressional Budget Office argues it is more efficient for the United States' purposes than a cap and trade program (2008). They argue that there are rising marginal costs to reducing emissions as firms use the cheapest ways to reduce emissions first. But the marginal benefit of having less emissions remains constant. In other words, a cheaply eliminated unit of emissions has the same effect on climate change as does a more costly eliminated one. A cap-and-trade program would be inflexible in its response to these rising marginal costs, while a tax would not be. These issues are, however, only tangentially related to the relationship between emissions-saving policy of either kind and their effects on R&D. Both seek to address only one of the two salient market failures.

The environmental market failure has been described in terms of an externality already. But R&D is associated with positive externalities as well. Addressing both externalities is considered the dominant strategy in the literature. For example, though there is substantial support for the development of emissions-saving technology in Europe (Bye & Jacobsen, 2011), R&D in the absence of environmental policies against pollution is likely to be below the socially optimal level (Jaffe, Newell, & Stavins, 2005).

Besides being politically expedient, emissions-saving R&D has an economic argument for its support instead of emissions reducing technology (Jaffe, Newell, & Stavins, 2005). If an effective carbon-abatement technology could be produced emissions reduction would be unnecessary. Yet this is unlikely as R&D is a product of investment and subject to two significant externalities. First, without emissions reducing policy, emissions-saving R&D would be unprofitable for any given firm. Secondly, R&D is subject to the externalities described by Romer in the following section.

3. Theoretical R&D Background: Endogenous Technological Change

A typical macroeconomics textbook will present a growth accounting equation in which the total output of the economy depends on factors like capital, labor, and productivity inputs. While the factors in my textbook that drive capital and labor growth get their own chapters endogenous growth theory, the study of factors that drive productivity growth, gets three pages (Abel, Bernanke, & Croushore, 2011, p. 206, 228-231). The disparity is not particularly surprising. Modeling endogenous growth is difficult, and challenges core macroeconomic assumptions. When Romer uses this model he explains that “price-taking competition cannot be supported” and so instead he finds an equilibrium under monopolistic competition (1989).

The conclusion Romer comes to which is of most interest is that too little human capital will be devoted to R&D in equilibrium. The theory is that this is because oftentimes the product of R&D is excludable, but nonrival. With R&D, this is often called knowledge spillovers. That is, using the patent system, a good produced by one firm’s research can be excluded from another, but the second firm’s consumption of that good does not rival the initial producer’s consumption of it. Because of this nonrival consumption knowledge spillovers are created. It follows from this that in perfect competition no private firm will participate in R&D. After all, there is nothing stopping the firm’s many competitors from stealing their research and thus matching their costs. When this happens, the researching firm has only the costs of research and no benefits from it. This is the reason the Solow model takes productivity as exogenous (Romer, 1989, p. 7).

Because of this market failure and environmental market failures, Jaffe et al. argue for a "portfolio of public policies that foster emissions reduction as well as the development and adoption of environmentally beneficial technology" (2005, p. 1). Adding the environment into the picture, however, complicates the picture of R&D spillovers somewhat:

> This means that a specified level of environmental cleanup can be achieved at lower total cost to society, and it also means that a lower total level of pollution can be attained more efficiently than would be expected if the cost of cleanup were higher. Thus, in this simple static picture, technology improvements can be good for the environment and good for the firm that must meet environmental mandates. (Jaffe, Newell, & Stavins, 2005, p. 166)

Thus there is a dynamic relationship between technology and environmental protection. Given that there is an interplay between R&D and emissions policy, it may be advantageous for a country to incentivize emissions-saving R&D in particular. In fact, this is exactly the question Bye and Jacobsen as well as Schneider and Goulder consider, as I describe in the following section.

Jaffe et al. break up the externalities associated with emissions R&D into knowledge and adoption externalities (2005). The knowledge spillovers are as they are described by Romer. The adoption externalities, however, may also have dynamic increasing returns. This stems from the fact that a technology diffuses gradually. Simply observing another firm using a new piece of technology can create a positive externality as the observer may become convinced that the technology is superior and subsequently reaps some benefit from it. There are also network externalities. Some technologies become more valuable as more people use them. Finally, there are "learning-by-doing" supply-side externalities. This refers to the fact that some technologies become easier to use with experience of using them. Together, these externalities mean almost all environmental economists recommend a combination of emissions-saving subsidies of some kind and emissions-reducing taxes or cap-and-trade policies. An early General Equilibrium Model employed by Schneider and Goulder makes just this argument (1997).

4. General Equilibrium Model

General Equilibrium Models (GEM) are a logical choice for the study of emissions control as any such control affects many markets. While partial equilibrium models are far more familiar to new students of economics, a carbon tax would influence not just those doing the actual emitting of carbon, but those selling products that use the energy of those emissions. The general equilibrium model allows for multiple markets to come to an equilibrium, allowing for the effects of emissions and emissions-related R&D to be examined while holding other markets constant.

An early GEM was used to argue that carbon taxes were a more efficient method of limiting emissions than R&D subsidies alone (Schneider & Goulder, 1997). They find that in a model that includes R&D spillovers, like the ones described by Romer, a carbon tax *and* a targeted R&D subsidy is the least costly emissions reduction strategy.

Schneider and Goulder note that a carbon tax alone does provide some incentive for R&D by correcting for environmental externalities (1997). This is because under carbon taxes firms have an incentive to reduce emissions and thus have a willingness to pay for technology that would allow them to do so. This may be of particular interest to policy makers as it is easier to sell a voter on R&D than it is to sell them on any tax. Unfortunately, the authors note, despite the relative unpopularity of a carbon tax a tax is still less costly than subsidies alone for the economy as a whole (see Table A1). In their short paper, however, they do not consider a *general* R&D subsidy. Bye and Jacobsen take up this case in their GEM and find that, in contrast, a targeted R&D is not socially optimal.

Bye and Jacobsen use the GEM to analyze the relationship between R&D and a carbon tax (2011). One complication of their study is induced technological change. That is, they do not make the normal assumption that technological advancement is outside of their model. Instead, they include two R&D support strategies: general and emission-saving.

They find that the general R&D support strategy is welfare superior but that the difference between general and emission-saving is smaller with high carbon taxes (see Table B2). This is an intuitive finding. Most economists would expect a less efficient result if a firm's options were restricted: the emissions-saving strategy is just such a restriction. The shrinking difference is also unsurprising. The substitution effect suggests that as emissions become more expensive consumers of R&D would the relatively expensive good (emissions) for the relatively inexpensive good (emissions-saving technology). This means the emissions-saving R&D strategy becomes less restrictive as even without it firms would prefer it to general R&D at higher carbon tax levels, ceteris paribus. Bye and Jacobsen argue that this is because the effects of decreasing returns to scale and decreasing returns to knowledge are more significant in the emissions-saving strategy.

Bye and Jacobsen take an emissions control that equals the "marginal environmental damages" of carbon emissions as granted. This means that the tax, in whatever form it is applied, would cost the polluter as much as the damage to the environment would harm everyone. A possible objection to their model is that they hold environmental quality constant in their policy simulations. While this may be realistic in the small open economy they are hypothetically creating, in a larger economy like the United States a policy change could have a measurable impact on environmental quality. Similarly, since a small open economy is their baseline (they use Norway), they assume any change in emissions quantity will not affect overall prices. This may not be a reasonable assumption for policy makers in the United States.

What Bye and Jacobsen call carbon capture technology (CCS) is the subject of the technological progress when their GEM uses the emissions-saving R&D. They cite an Intergovernmental Panel on Climate Change report for modeling several possibilities for such a technology. They use Norway from 2002 as the base economy, and model the different strategies as changes from that point on.

5. Conclusion

Proper execution of emissions-saving policy is nontrivial. Australia has recently made this quite evident. Robson writes that “Australia's carbon tax experience is an interesting case study in how not to go about implementing climate change policy” (2014, p. 43). And while R&D is a politically expedient answer to climate change legislation, the evidence does not support it being used alone. In Australia’s case, carbon permits were enacted on top of *and* in addition to new “complementary” emissions saving policies. The net effect of these changes were to increase energy prices, not reduce emissions, and damaged the government’s revenues (Robson, 2014). While action is needed, climate science must not be the only research consulted in making these decisions.

Further research on the relationship between climate change policies and R&D could add political capital to the environmental cause. By eliminating the perception that policy makers should choose between R&D and emissions control, and that they work best in tandem, an argument can be made for significantly more economically-grounded legislation. While Bye and Jacobson's research is a start in this direction, they use a model which has limited applicability to the United States, a major CO_2 producer. Extending their model could prove fruitful. Additionally, their model used a carbon tax, which at the moment is the most realistic. A cap-and-trade program, however, may have R&D advantages. As of yet no such research exists.

While the GEM has attractive features about it, a laboratory experiment allows for less assumptions than does a model which purports to simulate an entire economy. It has the additional benefit of circumventing criticism of the assumption that people are rational decision-makers by using actual people to make rational decisions. Such an experiment may also be able to incorporate the effects of political and technological uncertainty into the model. Such research is pressing since, as Schneider and Goulder point out, the costs of emissions control increase with time (1997).

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Appendix A

Table A1: Costs of 15% reduction in CO_2 emissions 1995-2095

Table 1 Costs of 15% reduction in CO_2 emissions 1995–2095

Model	*Carbon tax alone*	*Targeted R&D subsidy alone*	*Carbon tax plus targeted R&D subsidy of 10%*	*Carbon tax plus broad R&D subsidy of 10%*
1. No spillover from R&D	0.94	8.52	1.02	1.18
2. Spillovers from R&D only by alternative energy industry	0.66	5.98	0.60	0.78
3. Spillovers from R&D investment by all industries	1.03	9.55	1.09	0.81

Figures are percentage reductions to the present value of GDP. All simulations involve carbon tax rates that increase at a rate of 5 per cent annually to the year 2075 and remain constant thereafter. The carbon tax profile is the lowest path of (rising) tax rates that leads to the 15 per cent reduction in cumulative emissions relative to the baseline model. Model 1 evaluates costs when there are no spillovers from research and development (R&D) investments. In this case, the cheapest way to attain the 15 per cent abatement target is through a carbon tax alone. Model 2 assumes that there are significant spillovers from investments in R&D by the 'alternative energy' industry (the non-carbon-based fuel industry). In this case, the combination of carbon tax and R&D subsidy to alternative energy is the more cost-effective way to attain the target. Model 3 assumes all investments in R&D involve significant spillovers. In this case, the least-cost policy involves a combination of carbon tax and broad subsidy to R&D.

Source: Schneider & Goulder, 1997

Appendix B

Table B2: Long-run effects of the R&D policy shifts. Percent changes from the baseline scenario.

Carbon tax	12.5 euro		75 euro	
R&D policy shifts	General	CCS	General	CCS
Subsidy rate (change, per cent point rate):				
General R&D	0.05	− 0.04	0.04	− 0.04
CCS R&D	− 6.46	4.31	− 5.12	3.15
The R&D industries, production:				
Total R&D	0.13	− 0.05	0.00	0.07
General R&D	0.40	− 0.41	0.45	− 0.47
CCS R&D	− 44.38	57.71	− 41.70	51.03
The variety-capital industries, production:				
General R&D based capital	0.18	− 0.18	0.19	− 0.19
CCS R&D based capital	− 20.64	20.80	− 20.27	19.71
The R&D industries, prices:				
General R&D	− 0.05	0.05	− 0.05	0.04
CCS R&D	5.68	− 3.61	4.65	− 2.93
The variety-capital industries, prices:				
General R&D based capital	− 0.01	0.01	− 0.02	0.02
CCS R&D based capital	1.57	− 0.92	0.88	− 0.45
Electricity industries, production:				
Total	− 0.45	0.38	− 2.15	1.75
Gas power without CCS	0.81	− 0.69	3.13	− 2.52
Gas power with CCS	− 3.69	3.14	− 2.76	2.25
Power intensive industry, production	− 0.06	0.05	− 0.14	0.11
Electricity price	0.19	− 0.17	0.45	− 0.37
Welfare	0.003	− 0.003	0.0016	− 0.0026
CO_2-emissions	0.08	− 0.07	0.01	− 0.01

Source: Bye & Jacobsen, 2011