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Emissions Pricing, Spillovers, and Public Investment in Environmentally Friendly Technologies

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RESOURCES FOR THE FUTURE

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Abstract

In a second-best world of below-optimal pollution pricing, the public return to R&D may be greater than under Pigouvian pricing, due to excess benefits of increasing abatement, or it may be lower, since private actors lack the incentives to take full advantage of the new, cleaner technologies. This paper uses a simple model to demonstrate the interaction between environmental policies, R&D externalities, and the social return to innovation. The results indicate that strong public support for innovation is only justified if at least a moderate emissions policy is in place and spillover effects are significant. Furthermore, in most cases, policy constraints that limit regulatory burdens tend to further limit the scope for public support, even when cost reductions allow for more stringent abatement targets. An exception is when knowledge of the policy adjustment process further reduces private innovation incentives.

Key Words: emissions price, technological innovation, spillovers, R&D policy

JEL Classification Numbers: Q28, O38, H23

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1. Introduction

Public investment in research and development (R&D) is often driven by the fact that the social value of innovation often surpasses what the innovators themselves can appropriate. Studies of commercial innovations suggest that, on average, only about half of the gains to R&D return to the originator, although appropriation rates vary considerably over different types of innovations.[1] With respect to innovations that may benefit the environment, this rationale of spillover effects is combined with the argument that, since the damages of emissions are not fully internalized by private markets, there is an added impetus for public investment in less polluting technologies.

Research in environmental economics on technological change has focused on the private and social incentives for innovation created by different environmental policies.[2] Innovation incentives are recognized as important criteria for policy selection,[3] and market-based environmental policies are revealed to perform better than command-and-control regulation.[4] Several papers compare innovation and adoption incentives among different market-based instruments, like emissions taxes and auctioned or grandfathered permits.[5] Typically, they assume that the tax or emissions price achieves some level of optimality with respect to pollution abatement, at least in some (often pre-innovation) sense, if not in the dynamic sense.[6] Alternatively, the environmental policy goal may be to achieve a second-best solution in the

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[1] See Griliches (1992) and Nadiri (1993), as well as Hall (1996).

[2] For more discussion of the literature, see Kemp (1997) and Ulph (1998).

[3] Stavins (1998), Bohm and Russell (1985).

[4] See, e.g., Downing and White (1986), Magat (1978) and Zerbe (1970) for comparisons of market-based policies to command-and-control regulations.

[5] See, e.g., Milliman and Prince (1989), Biglaiser and Horrowitz (1995), Jung et al. (1996), Fischer et al. (2003), Requate and Unold (2002).

[6] Some of the dynamic problems are addressed in Petrakis and Xepapadeas (1999) and Kennedy and Laplante (1999).

presence of an externality in the market for R&D, where direct R&D policies are either absent or insufficient to target the specific environmental and innovation problems.

Meanwhile, in reality, environmental externalities are often under priced; occasionally, public subsidies may actually exacerbate them.[7] Not surprisingly, innovation in "environmentally friendly" technology is then lacking. Consequently, governments use various innovation and adoption incentives to make up for the shortfall. These tools may include direct subsidies, tax credits, technology forcing regulation, and price or market share guarantees for the use of particular technologies.[8] Often, where political constraints prohibit policies from creating significant costs to business for polluting behavior, innovation subsidies are then sought out with greater urgency to try to correct the environmental problem.

Parry et al. (2003) show that the total gains to innovation are naturally limited to the current costs of abatement and the benefits from eliminating the remaining emissions. These potential gains are further reduced by the fact that innovation and diffusion are lengthy—and costly—processes, and future benefits are discounted. Thus, in few situations are the gains to innovation large compared to the current gains from internalizing the pollution externality. However, those relative gains can be quite different when policies do not take advantage of all the current gains from abatement.

While there is a growing consensus that pricing emissions creates private incentives for innovation, it is not well understood how emissions pricing (or lack thereof) affects the *social* premium to innovation. In a second-best world of below-optimal pollution pricing, the public return to R&D may be greater, due to the excess benefits of increasing abatement; on the other hand, it may well be lower, since private actors will still not have the incentives to take full advantage of the new technologies that are developed. This paper uses a simple model to demonstrate the interaction between environmental policies, R&D externalities, and the social return to innovation.

The next section analyzes the social and private returns to innovation as a function of the spillover rate and degree of emissions pricing, when those prices are fixed. It reveals that a good deal of public support for R&D tends to be warranted only if the emissions price reflects a

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[7] Fischer and Toman (1998).

[8] Many of these examples have been used to promote renewable energy sources and low- or zero-emissions vehicles.

significant share of the damages and spillovers are important. Section 3 evaluates those returns when technological progress enables regulators to make environmental policy more stringent. In most cases, when policies adapt to cost changes according to political constraints, both the social and private gains from innovation fall, though the role for public investment is enhanced as a consequence. The final section offers conclusions.

2. Model

We use a transparent model of linear benefits and marginal costs of abatement to solve for the social premium to innovation—that is, the additional social return above and beyond the private return—given a rate of emissions pricing and of spillovers. Since the focus will be on the marginal gains from abatement and the returns to lowering abatement costs, we can abstract from the costs of innovation and inframarginal emissions, albeit recognizing that they affect the optimal equilibrium levels of innovation and welfare. We consider the private and social innovation incentives under an emissions tax, which allows total abatement to respond to cost changes; if the regulation instead set a quantity target, the only discrepancy between the two returns to innovation would be the spillover effects.

Assume that abatement, A, has constant marginal benefits to society of b. Let the costs of abatement be

$$C(A) = \frac{c(1-r)}{2}A^2 \tag{1}$$

where c is the initial slope of the marginal abatement cost curve and r is the rate of potential cost reduction.

Let p be the price of emissions (and the value of abatement to the firm). The firm must pay this price on all of its initial emissions, M, net of abatement and any freely allocated (grandfathered) permits or tax threshold, F. This policy could be set up as a tax or emissions permit program, or a subsidy, in which case the net emissions liability ($M-F$) is less than abatement. The important assumption for now is that this emissions price is fixed.[9] Consequently, the net emissions liability does not affect incentives and can be ignored.

[9] We will relax this assumption in the next section, looking at endogenous policy adjustments.

The private market, portrayed here as a representative firm, chooses the level of abatement to maximize profits:

$$\pi = pA - \frac{c(1-r)}{2}A^2 - p(M-F) \tag{2}$$

leading to

$$A = \frac{p}{c(1-r)} \tag{3}$$

Rewriting profits, we get

$$\pi = \frac{p^2}{2c(1-r)} + p(M-F) \tag{4}$$

Let us assume that a private innovator can capture $1-\sigma$ of the private gains to reducing costs, where σ is the spillover rate.[10] Thus, the private innovator's gains to increasing *r* are

$$\frac{\partial \pi}{\partial r} = \frac{(1-\sigma)p^2}{2c(1-r)^2} \tag{5}$$

Social welfare is

$$W = bA - \frac{c(1-r)}{2}A^2 = \frac{p(2b-p)}{2c(1-r)} \tag{6}$$

The social return to innovation is reflected in the additional gains from reducing costs:

$$\frac{\partial W}{\partial r} = \frac{p(2b-p)}{2c(1-r)^2} \tag{7}$$

Let $p = \phi b$, where ϕ is the share of the marginal damages reflected in the market price of emissions. We define the social premium, *R,* for cost reductions as the difference between the social and private values for reducing abatement costs a bit more:

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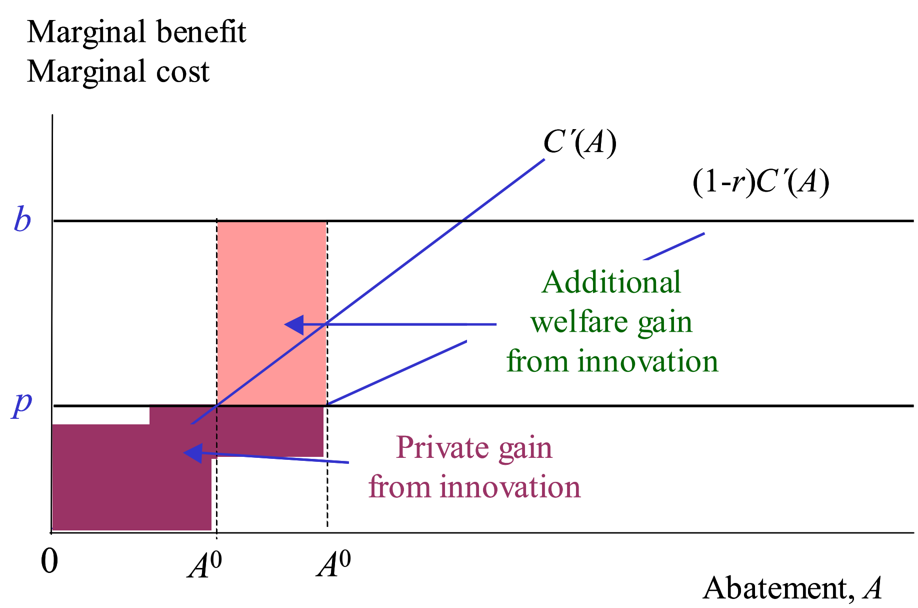
[10] Fischer et al. (2003) note that in a market equilibrium in which the technology may be adopted or imperfectly imitated, the effective appropriation rate will be endogenous. However, for our purposes we will take it as given.

$$R = \frac{\partial W}{\partial r} - \frac{\partial \pi}{\partial r} = \phi(2-\phi(2-\sigma))G^* \quad (8)$$

where $G^* = \frac{b^2}{2c(1-r)^2}$ is the welfare gain from an additional percentage reduction in costs at Pigouvian emissions pricing. Note that while the slope of the marginal cost and benefit curves are essential for determining the marginal gains to innovation, the share that is the social premium is invariant to all but the rate of emissions pricing and spillovers. Similarly, this share will also be invariant to other factors that might affect the level of the marginal gains to innovation in a multi-period model, as discounted flows or lagged benefits will have proportional impacts on G^*. Thus, although we have a single-period model, we can think of A as being abatement over the horizon relevant for the innovation, and p and b as representing the (expected) discounted prices and marginal damages over that horizon.

Graphically, we see that the marginal social gains to innovation include the private gains (inclusive of spillovers), as well as the difference between marginal benefits and the price of abatement, multiplied by the additional abatement that occurs with lower costs.

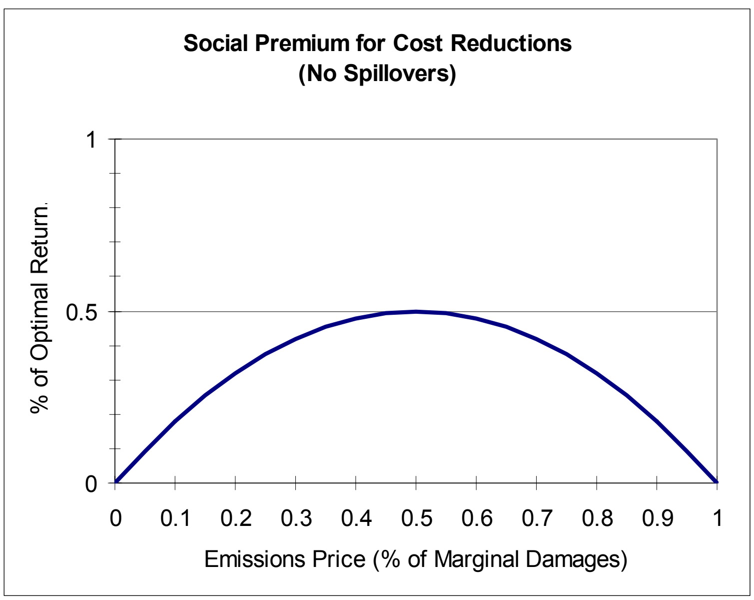
Figure 1: Gains to Abatement Cost-Reducing Innovation



In the following series of figures, we explore how the social premium—expressed as the percentage of the marginal social value of innovation when the marginal cost of the externality is fully internalized—varies with the two parameters of concern: the rate at which the price reflects marginal damages, and the spillover rate.

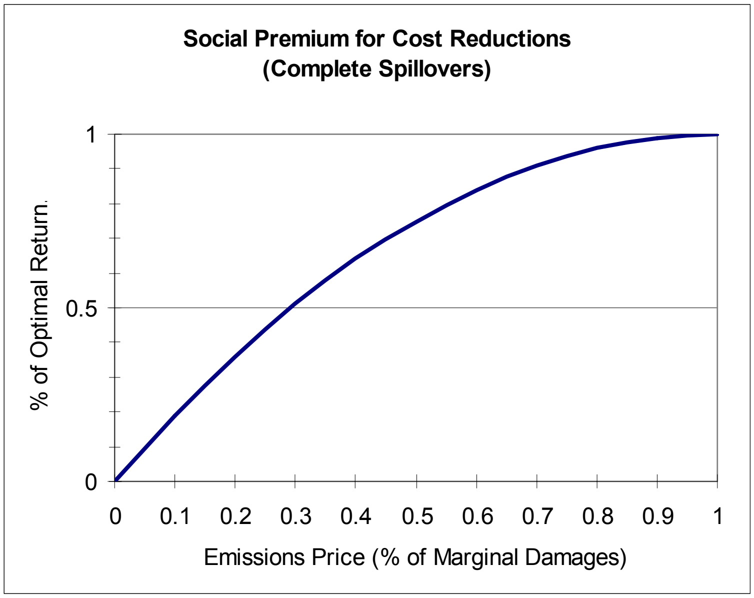
When innovators in the private market can capture all the returns to their R&D, the social premium displays an inverse U-shaped function with respect to the rate of internalization of the externality. Logically, if emissions are not priced at all, any innovation will not be used, so investment is not worthwhile. Meanwhile, if emissions are fully priced, the private market has sufficient incentive to invest, so no social premium exists. Correspondingly, the social premium remains small when the emissions price is very far or very close to the Pigouvian level, and it is highest when the emissions price is about half of marginal damages.

Figure 2



On the other hand, if the private market has no incentives of its own to innovate, since spillovers are complete, the social gains from abatement cost reduction increase monotonically with emissions pricing (up to the Pigouvian level). Furthermore, if about a third of the marginal damages are priced, the marginal benefits of reducing costs are at least half those with full emissions pricing (see Figure 3).

Figure 3



In an in-between case, suppose half of the returns to cost reductions are captured by private innovators, as is the estimated average for commercial innovations. As in all cases, at low rates of emissions pricing, little social premium exists for reducing abatement costs.[11] However, once a third of the marginal damages are priced, the social premium is over half the returns under Pigouvian pricing. This remains true, even as the premium declines from its peak as Pigouvian pricing is reached, due to the fact that innovators can only capture half the private gains to abatement cost reductions.

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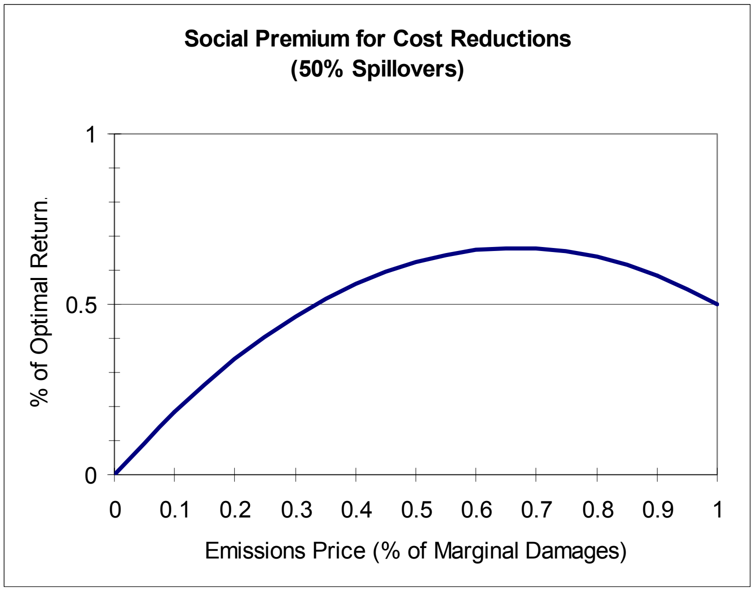
[11] Mathematically, we see that the emissions price ratio that induces the largest social premium for innovation is $\hat{\phi} = 1/(2-\sigma)$.

Figure 4



Thus, with linear benefits and marginal costs, if spillovers represent half or more of the value of innovation, the social premium to innovation will exceed half of the total return under Pigouvian pricing, as long as at least a third of the marginal damages are reflected in the price of emissions. On the other hand, if less than 30% of the marginal damages are internalized, the social premium for innovation is always less than half of the Pigouvian return. In other words, strong support for innovation is only justified if at least a moderate emissions policy is in place and spillover effects are significant.

For example, suppose the marginal damages from greenhouse gas emissions are $50 per ton of carbon. That price is equivalent to $25/ton of coal; if the base cost of coal is roughly $30/ton, and no carbon tax is imposed, then 55% of the social cost of coal is reflected in the price. In this case, there would be additional social benefit from innovation to reduce reliance on coal, above the private savings from reduced input use, and spillovers from fuel-saving techniques or technologies would add to the social premium. On the other hand, from the point of view of reducing the carbon emissions from the use of coal (i.e., “end-of-pipe” technologies like sequestration), without any incentive to use them, little is to be gained from innovation. Of course, assessing the appropriate time horizons of the innovation and the policies is also important here.

For innovations that improve current technologies, the emissions policies of the near term are the determining factors. However, for technological advances that have longer-term implications—or might replace current technologies—what matters are expectations about the policies that will be in place when the invention can be commercialized. Thus, even without carbon pricing now, the expectation of prices in the future can make current public R&D support worthwhile. Furthermore, it may be that those policies will be influenced by the future state of abatement costs.

3. Endogenous Policy Constraint

This analysis of the effect of below-optimal emissions pricing on the social return to innovation is underpinned by an assumption that policymakers are inhibited from imposing the full social cost of pollution on the emitters. It is therefore also important to explore the reasons for the political constraint, and how policy might respond to changes in abatement costs. Indeed, another argument for public investment in environmentally friendly technologies when emissions prices are low is that it can make more stringent regulation politically viable. Stakeholders are likely to resist policies that are too costly, so if abatement becomes cheaper, they may accept harder targets. Similarly, policymakers may resist abatement subsidy programs that cost too much in public funds; lower-cost abatement technology can in such cases enable the purchase of more abatement.

In this section, we evaluate the social premium to innovation when the environmental regulation adjusts to the policy constraint. We continue to abstract from questions of the policy horizon and discounting; although these dynamic issues are certainly important, the key intuition is summarized in this simple, three-stage game of policy adjustment. In the first stage, the firm or the social planner chooses an amount of innovation. In the second stage, the regulator adjusts the emissions price, abatement target, and allocation of emissions permits. In the third stage, the firm conducts abatement, and profits and welfare are realized. In this framework, let us analyze the innovation incentives under different policy adjustment mechanisms.

The previous section's analysis of constant emissions prices supposes, in effect, that policymakers are constrained by the marginal abatement costs they may impose on polluters. This might arise from a focus on marginal *production* costs, out of concern for industrial competitiveness or the burden on consumers, since, when emissions are a function of output, marginal abatement and tax costs are reflected in higher output prices.[12]

Suppose instead that the policy concern is the total cost burden of regulation, resulting in a constraint that profits be held constant at the initial level of regulation. Here, then, it is important to account for the distribution of the emissions rents. Since taxing inframarginal emissions only reduces profits and thereby the scope for costly abatement under this constraint, let us assume that the policymaker implements a tradable emissions permit scheme and allocates the permits to the firm in a lump-sum fashion.[13]

Formally, let $F = M - A$. Since no permit liability remains with grandfathered permits, the net costs are simply those of abatement. After innovation, profits with grandfathered permits are

$$\pi^F = -\frac{c(1-r)}{2}A^2 = -\frac{p^2}{2c(1-r)} \quad (9)$$

Let p_0 be the initial permit price. Initial profits are then defined as $\pi_0^F = -p_0^{\,2}/(2c)$. As abatement costs fall, the policymaker tightens the emissions abatement requirement (thereby adjusting the price), maintaining constant profits, such that $\pi^F = \pi_0^F$. We note that with linear marginal costs, this policy constraint is equivalent to what would arise if total abatement subsidies (*pA*) had to be constant. Although the constant level of profits to the firm would be different,[14] the policy adjustment response to cost reductions (which determines the innovation incentives) would be the same in either scenario. Let us represent this equilibrium with the accent "~". That adjusted price is

$$\tilde{p} = p_0\sqrt{1-r} \quad (10)$$

[12] To see this result, suppose $M = mQ$. Then $\pi = p(A + F - mQ) - c(1-r)A^2/2$ and $\partial\pi/\partial Q = -pm$. To keep this regulatory burden on marginal production costs constant, *p* must also be constant. Allowing total abatement to also be a function of output does not change this result; according to the Envelope theorem, since profits are optimized with respect to abatement, small changes in abatement due to output changes do not affect profits.

[13] Equivalently, an emissions tax could be levied on emissions above a grandfathered amount, with refunds available below. With automatic adjustment to cost changes, the two policies will be identical.

[14] With a subsidy program and $F = M$, profits would be $\pi = p_0A_0 - p^2/(2c(1-r))$.

Note that this constraint implies that the permit price falls as costs fall, but not to the full extent of the price reduction, since some of the reduction is used to allow abatement to increase.[15]

From the social standpoint, constrained welfare is

$$\widetilde{W} = \frac{bp_0}{c\sqrt{(1-r)}} - \frac{p_0^{\,2}}{2c} \tag{11}$$

and the gains to cost reductions are

$$\frac{\partial \widetilde{W}}{\partial r} = \frac{bp_0}{2c(1-r)^{3/2}} \tag{12}$$

If industry realizes the policy response to cost reductions, it will have no incentive to innovate, so the social premium equals the marginal welfare gain from cost reductions. Thus, this expression is the maximum possible social premium, since any private innovation that occurs (such as due to myopia) would reduce the social need for innovation. To compare to the social premium with exogenous policy, we can rewrite

$$\frac{\partial \widetilde{W}}{\partial r} = \phi G^{*}(1-r)^{1/2} \tag{13}$$

where $\phi = p_0 / b$.

In this case, the return to innovation is a linear function of the rate of emissions pricing. Furthermore, the slope falls as more innovation occurs. At its maximum level—before any cost reductions occur—the social premium is the identity line in Figure 3, which lies strictly below that with complete spillovers and no endogenous policy effect. In fact, we can show that the social return to cost reductions is always smaller with policy adjustment than without when $\sigma = 1$:

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[15] If a tax is levied on inframarginal emissions, the constant-profit constraint could allow prices to rise as costs fall. However, this implies that to maintain any level of profits, the emissions tax must be lower to account for the transfer payments, resulting in less abatement/thereby forgoing some abatement.

$$\frac{\partial \widetilde{W}}{\partial r} - \frac{\partial W}{\partial r} = ((1-r)^{1/2} - 2 + \phi)\phi G^* < 0 \tag{14}$$

Since the permit price falls as policy is adjusted, the return to innovation is lower than it would be if the price remained fixed. In another sense, since costs are fixed, there exist no gains from reducing abatement costs, only from increasing abatement.

If we compare this return to the social premium without spillover effects ($\sigma = 0$), we get

$$\frac{\partial \widetilde{W}}{\partial r} - R = ((1-r)^{1/2} - 2(1-\phi))\phi G^* \tag{15}$$

The premium with endogenous policy is lower than with exogenous policy when $\phi < 1/2$, but may be higher for higher levels of emissions pricing. In other words, reduced costs lead to higher levels of abatement when prices are fixed, so additional innovation leads to larger increases in welfare with exogenous policy. However, when marginal damages are more fully priced, the private market has better incentives to innovate when prices are fixed, while the government must provide the support for innovation when price adjustments are expected.

For another example, suppose instead that the policy alternative is a fixed quantity of abatement, rather than a fixed price, and denote this equilibrium with "^". In this case, $\hat{p} = (1-r)p_0$. The return to the industry from innovation is positive:

$$\frac{d\hat{\pi}}{dr} = (1-\sigma)\frac{{p_0}^2}{2c} = (1-\sigma)(1-r)^2\phi^2 G^* > 0 \tag{16}$$

Thus, comparing to the constant-cost policy,

$$\hat{R} - \frac{\partial \tilde{W}}{\partial r} = \left(\sigma(1-r)^2 - (1-r)^{1/2}\right)\phi G^* < 0 \tag{17}$$

In other words, the absence of the opportunity to expand abatement, combined with the presence of some private incentives to innovate, means that less of a role for public investment exists under a fixed quantity policy than when emissions policy adjusts to keep costs constant. Of course, this comparison assumes that the initial price of permits, which reflects the constraint on policymakers, is the same.

Some of these results are not so surprising. As is well recognized in the literature on innovation incentives, a fixed-price policy induces more innovation than when prices decline, the most extreme case of which is a fixed-quantity policy, when permit rents are grandfathered.[16] The reason for this phenomenon is that abatement expands most when emissions prices remain fixed. A constraint on policy that limits costs or limits abatement then calls for less innovation. Only if the constraint (or specifically the adjustment to the constraint) eliminates more private incentive than social return does the social premium to R&D rise.

Perhaps more surprising is that it is difficult to find a simple economic motivation for a political constraint, such as concern for the total or marginal costs of regulation, that would call for emissions prices to rise and generate a larger social benefit to innovation than a currently fixed emissions price—even a below-optimal one. The idea that innovation can allow regulators to impose much more stringent regulation (that is, expanding abatement to the extent that emissions prices and marginal costs rise) would have to rest on more complex political motivations or cost structures. For example, if initiating an emissions policy involves significant fixed costs, one might want to delay implementation until innovation enables sufficiently significant abatement benefits. Private incentives to delay the regulation then reduce (or eliminate) their incentives to innovate. The social premium can then be bolstered by the lack of private innovation and the desire to implement the policy.

More generally, if innovation does allow regulators to raise prices, additional public support for environmental R&D can indeed be called for. Abstracting from the underlying motivations, suppose that we have $p(r)$, where $p'(r) > 0$ and $p(0) = p_0$. Then the social return to initial innovation is larger than with the fixed price, adding to Equation (7) the term $b(1-\phi)p'(0)/c$. On the other hand, if only the price is adjusted, leaving the baseline emissions liability unchanged, the private return to innovation may be higher or lower. Added to Equation (5) is $(1-\sigma)(\phi b - c(M-F))p'(0)/c$, the sign of which depends on whether that baseline liability is smaller or larger than initial abatement. If the polluter receives an abatement subsidy, the net effect on the social premium may be ambiguous, since some private incentives exist to raise the

[16] See, e.g., Fischer et al. (2003). Some subtleties arise in the structure of innovation and adoption markets when comparing private incentives from market-based instruments. Quantity policies may induce more private innovation when permits are auctioned, if innovators recognize that they can reduce their own emissions payments, and those savings outweigh the lower royalties they can charge adopting firms when prices fall. In this case, additional private incentives to innovate in a fixed-quantity policy would further reduce the social return.

emissions price, thus increasing the value of the subsidy. If the polluter is a net emissions taxpayer, however, the social premium to innovation is necessarily raised.

In summary, using innovation policy to promote stronger environmental policy does not always imply a bigger return to public investment in R&D. Only if emissions prices can rise are the overall welfare gains from additional innovation larger. On the other hand, the social premium may rise in more cases: if the adjustment policy is known, unless abatement subsidies rise as costs fall, private incentives are lessened.

4. Conclusion

A good deal of emphasis in environmental policy is placed on promoting technological solutions that reduce the costs of emissions abatement. While the true costs and benefits of emissions reductions determine the scope of the gains from lowering abatement costs, the actual returns to investments depend as much on the environmental policy environment. This simple exercise reveals that the relative importance of a public role for environmental R&D is highly sensitive to both the degree to which the emissions externality is internalized for private markets and the extent to which spillovers prevent private actors from reaping the full benefits of their innovations.

Private incentives to reduce abatement costs depend on how expensive emissions are and to what extent they can capture the gains to their innovations. If the price of additional emissions does not reflect the full social cost, less abatement will be performed, creating less incentive to reduce abatement costs. Spillover effects further reduce the private incentive to innovate. From a social perspective, insufficient abatement means that more is to be gained from cost reductions that expand abatement, since the marginal benefits outweigh the costs; however, since a cost reduction will have less of an impact when abatement is low, there is also less scope for cost savings.

As a result, the role for publicly supported innovation is strongest when some spillover effects are present and at least a moderate share of the marginal damages of emissions is reflected in the price. At the extremes, if emissions are unpriced, even if spillovers are complete, no public support for R&D to reduce abatement costs is justified, since the innovations will not be used. If emissions are fully priced and there are no spillovers, then no market failure remains to justify public support. However, most cases will tend to fall in between. For example, the cost of electricity reflects a significant but incomplete share of the total social costs, inclusive of the estimated marginal damages. Furthermore, there are likely to be significant spillovers in energy-saving technologies. The combination implies a reasonable scope for public investment in energy-saving innovations. It also implies greater scope for increasing the effectiveness of such investments by more fully pricing the externality.

If the degree of regulation is constrained by the costs (either private or fiscal), then innovation can allow for stricter abatement targets. However, this adjustment process does not tend to expand abatement as much as under fixed emissions prices, so the returns to public investments tend not to be as great. On the other hand, if the alternative were a fixed quantity policy, the opportunity to adjust and expand abatement would create greater value to R&D. Furthermore, if firms expect the adjustment and thereby do not want to innovate themselves, the role for public investment is larger, particularly if spillovers would not otherwise be important. However, in many circumstances, this role can be greater if emissions prices were fixed, even at a below-optimal level. And if technological progress can help stakeholders accept an even higher emissions price, closer to the damage costs, public support for R&D can be yet more worthwhile. Ultimately, it is the pricing of emissions to reflect the environmental burden that improves welfare.

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