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Frameworks for Analyzing the Effects of Risk and Environmental Regulations on Productivity

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By W. KIP VISCUSI*

Although regulatory agencies have promulgated health, safety, and environmental regulations largely on the basis of their presumed benefits, the adverse economic effects of these policies are becoming an increasingly prominent concern. A series of studies has linked these regulations to the productivity slowdown, inflation, and unemployment.[1] Significant economic effects of this type should be expected since the present value of the costs associated with major risk and environmental regulations proposed between 1975 and 1980 was \$332.2–\$846.5 billion.[2] These cost impacts are both quite large and highly variable. My concern in this paper is with how both the level of these costs and their uncertainty affect productivity.[3]

The existence of a negative relationship between the regulatory burden and capital investments, and consequently productivity, is not controversial. A conventional model of this type is developed in Section I. If, however, these regulations change over time and firms' investment decisions are irreversible, there will be additional distortions, as shown in Section II. In Section III, I show that uncertainty regarding these regulatory changes exacerbates the adverse productivity effects even for risk-neutral firms.

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[1]These studies include Edward Denison (1978), Robert Haveman and Gregory Christainsen (1980) Marvin Kosters (1980), Paul MacAvoy (1979), Peter Pashigian (1981), and Paul Portney (1980).

[2]I present this estimate in my 1983 study.

[3]The role of regulatory uncertainty is often stressed by businessmen. As George P. Shultz observed, it introduces "a real wild card in investment decisions" (1980, p. 14).

I. Regulatory Impacts with Reversible Investments

If firms' investments are completely reversible, we can treat the firm as if it were renting capital on a period-by-period basis. This can be done using either a single period model, or, in a multiperiod context, by assuming that the firm is myopic. In this section, I develop a fairly conventional model of this type to establish a point of reference for the subsequent results. Consider firms with two choice variables, the output level q and the quality level z, which will be scaled without loss of generality so that z is in the interval $[0,1]$, where higher values of z represent higher quality levels. For risk regulations, the value of $1-z$ represents the risk level per unit of output, such as the product failure probability or the injury rate per worker.[4] For environmental situations, $1-z$ can be viewed as the level of pollution per unit of output.

The firm sells its output at a price v, and incurs production costs $C(q)$, where $C(q) \geqslant 0$, $C' > 0$, and $C'' > 0$. Raising the quality level z is also costly, with the unit cost of producing quality z being given by $G(z)$, where $G(z) \geqslant 0$, $G' > 0$, and $G'' > 0$. Finally, firms are penalized x per unit of risk or pollution, so that the overall regulatory penalty is $xq(1-z)$. The value of x represents the total quality-related penalty, including rewards transmitted through market forces, but for concreteness I will treat the entire value of x as a policy parameter. If x reflects the value society places on each unit of quality, the regulatory policy will lead to an efficient outcome. The financial incentives imposed by workers' compensation sys-

[4]In the case of job safety, one can easily modify the formulation below so that the firm picks the number of workers L rather than the output level q.

tems or by proposed pollution tax policies best fit this structure. The model is also applicable to standards policies for which the penalties are linked to the extent of noncompliance once we reinterpret z as the degree of regulatory compliance.[5]

Firms consequently select the level of q and z to maximize profits π^0, or they

$$\text{(1)} \qquad \underset{q,z}{\text{Max}}\, \pi^0 = vq - C(q) - qG(z) - xq(1-z),$$

yielding first-order conditions that reduce to[6]

$$\text{(2)} \qquad C' = v - G(z) - x(1-z);$$

$$\text{(3)} \qquad G' = x.$$

For given quality level z, the regulation lowers the marginal benefits of production (or raises the marginal costs if one rearranges equation (2)), lowering the optimal output level. As equation (3) implies, the optimal quality level is set where its unit cost equals the regulatory penalty x. Finally, more stringent regulatory penalties will raise the overall quality level and depress output, as

$$\partial z/\partial x = 1/G'' > 0$$

and

$$\partial q/\partial x = -(1-z)/C'' < 0.$$

II. Irreversible Decisions and Changes in Regulatory Policies

If there are no impediments to changes in the firm's decisions, shifts in regulatory policies can be assessed using a one-period model as in Section I. Firms usually have much more limited discretion. Modifications in plant capacity, particularly in the downward direction, are typically quite costly due to the specialized nature of the capital stock, transactions costs involved in its resale, and the absence of a strong resale market. Similarly, once a firm has complied with risk and environmental regulations by, for example, installing a ventilation system to control hazardous fumes, the costs of compliance represent a sunk cost that cannot be readily recovered.

Although the degree of inflexibility spans a continuum of possibilities, both in the upward and downward directions, I will focus on irreversibilities, where there is complete downward inflexibility in the enterprise's decision. Under this formulation, which was introduced by Kenneth Arrow (1968), the firm cannot reduce past capital investments, but it is free to augment these investments. This asymmetric approach is intended to be an approximation to the greater difficulties associated with decreasing past investments. While these investments may not be characterized by complete downward inflexibility, as the transactions costs of disinvestment increase, the results approach those under strict irreversibility.

Consider firms making decisions in a two-period model. Since in a single period, $C(q)$ and $G(z)$ represented the capital stock rental costs for one period, I will treat the role of irreversibility as making the first-period choice of q and z tantamount to a rental commitment that it cannot reduce.[7] If we denote the two periods by subscripts i, where $i=1,2$, the irreversibility assumption is that $q_2 \geqslant q_1$ and $z_2 \geqslant z_1$. Once an enterprise selects an output or quality level, it cannot reduce it.

A. *Increasing Regulatory Stringency*

Suppose that firms are aware that the regulatory penalty will rise from x in period 1 to x^* in period 2, where $x^* > x$. Regulatory policies that are phased in over several years have this character, as policymakers attempt

[5]The only additional complication is that corner solutions play a more important role in the case of standards. For firms that choose complete compliance, the penalty term involving z drops out of the analysis, but the unit cost terms remain, where an optimizing firm will set z at the minimal level to ensure compliance in this instance.

[6]The second-order conditions are also satisfied since $\pi^0_{qq} < 0$, $\pi^0_{zz} < 0$, and $\pi^0_{qq}\pi^0_{zz} - (\pi^0_{qz})^2 = qC''G' > 0$.

[7]In a two-period model, this approach gives much more realistic results than examining actual capital investments since investments in the first period will have a longer useful life. In addition, as in the case of Arrow's analysis (p. 5), I will abstract from the influence of depreciation since it plays no essential role.

to ease the adjustment burdens on the affected industries. Increasing the regulatory penalty will enhance the attractiveness of quality investments and will diminish the incentive to make capacity investments by raising the regulatory burden per unit of output. Since the firm cannot reduce its output level, it will remain at whatever level is selected in period 1, or

$$(4) \qquad q_2 = q_1.$$

An optimizing firm will, however, raise z in the second period. The cost functions remain the same as before, but I will sometimes use the notation G_i to denote $G(z_i)$, and similarly C_i for $C(q_i)$.

I will follow the usual dynamic programming approach of considering the decisions in the second period, given the first-period choices, and then work backwards to analyze the optimal first-period choices. The value of z_2 is picked to maximize the profits π^* in the second period, or

$$\underset{z_2}{\operatorname{Max}} \pi^* = vq_1 - C(q_1) - q_1 G(z_2) - x^* q_1 (1 - z_2),$$

yielding

$$(5) \qquad G_2' = x^*.$$

This equation, which is the second-period analogue of equation (3), indicates the optimal z_2 level as a function of x^*. Equation (5) thus implicitly defines a function $Z(x^*)$, which gives the optimal value of z_2 as a function of x^*, where $Z' > 0$. It is noteworthy that z_2 depends only on x^* and not on any other parameters or on any decisions in period 1. The optimal decisions in period 2 are defined by equations (4) and (5).

The task in period 1 is to maximize discounted expected profits $\hat{\pi}$, where the discount factor β is the inverse of one plus the interest rate. The values of q_1 and z_1 are selected to

$$\underset{q_1, z_1}{\operatorname{Max}} \hat{\pi} = vq_1 - C(q_1) - q_1 G(z_1) - xq_1(1 - z_1) + \beta[vq_1 - C(q_1) - q_1 G(Z) - x^* q_1 (1 - Z)],$$

leading to first-order conditions that can be rewritten as

$$(6) \qquad G_1' = x;$$

$$(7) \qquad C_1' = v - \frac{G_1 + x(1 - z_1) + \beta G_2 + \beta x^*(1 - Z)}{1 + \beta}.$$

As regulations become more stringent, ideally firms would like to expand their quality investment and diminish their capacity investment. The increase in the quality investment is feasible, as firms select z_i on a myopic basis in each period (equations (5) and (6)) based on the regulatory penalty and marginal investment costs. These quality investments are independent of the output level so that the first-order conditions are not mutually dependent; the z_i values affect capacity, but there is no reverse linkage. Since capacity investments cannot be diminished, there is no additional investment in period 2, and the capacity level for both periods is selected in period 1 to satisfy equation (7).

The fundamental concern here is how the resulting capacity investment levels compare with those under the reversible cases. Because of the recursive nature of the results (i.e., the z_i influence q_1 but are not affected by it), this relationship hinges only on the capacity investment first-order conditions. The condition that the terms on the right side of equation (2) exceed the right side of equation (7) reduces to

$$G(z(x)) + x(1 - z(x)) < G(Z(x^*)) + x^*(1 - Z(x^*)) \equiv H,$$

or showing that the quality-related costs per unit of output are greater in situations in which x is increased to x^* than in one-period problems. To prove that H is increasing in x differentiate and apply the envelope theorem, yielding

$$(8) \qquad dH/dx^* = 1 - Z > 0.$$

The prospect of tighter regulations depresses the value of q_1, compared with the reversible case, as the expression on the right-hand side of equation (2) always exceeds the comparable terms in equation (7).[8]

Upon total differentiation of equations (6) and (7), it can be shown that

$$\partial z_1/\partial \beta = \partial z_1/\partial x^* = 0,$$
$$\partial q_1/\partial \beta < 0, \quad \text{and} \quad \partial q_1/\partial x^* < 0.$$

The policy shift in period 2 does not alter z_1, but it does depress the optimal output level. An enterprise facing a schedule of increasingly stringent regulations will reduce its initial output level and be myopic in its quality investments. Increasing the discount factor places a greater weight on these second-period choices, leading to a reduction in the output level.

B. *Decreasing Regulatory Stringency*

When regulations are loosened rather than tightened, there are many similarities in the technical aspects of the analysis, but some significant differences in the nature of the results. If the penalty falls from x to x_* in period 2, where $x > x_*$, the firm cannot reduce z, so that $z_2 = z_1$, but it can increase its output level. It will do this in period 2 to maximize second-period profits π_*, or

$$\underset{q_2}{\operatorname{Max}} \pi_* = vq_2 - C(q_2) - q_2 G(z_1) - x_* q_2(1 - z_1),$$

yielding

$$(9) \qquad C_2' = v - G_1 - x_*(1 - z_1).$$

Equation (9) implictly defines the optimal q_2 as a function of x_* and z_1, where

$$\partial q_2/\partial x_* < 0;$$

$$\text{and} \quad \partial q_2/\partial z_1 = (x_* - G_1')/C_2'' < 0.$$

This relationship will be denoted by $Q(x_*, z_1)$. The effect of z_1 on q_2 involves two competing effects. I will show below that the marginal penalty x_* per unit of quality is smaller than the increased unit cost of quality G_1' at the optimal z_1. This gap arises since the firm will overinvest in z_1 in period 1 relative to the quality investment it would have chosen if the penalty were always x_*. As a result, the high quality investment commitment from period 1 depresses output in period 2 since the marginal costs imposed by z_1 exceed the marginal reduction in regulatory penalties in period 2.

The decision in period 1 is to

$$\underset{q_1, z_1}{\operatorname{Max}} \pi^{**} = vq_1 - C(q_1) - q_1 G(z_1) - xq_1(1 - z_1) + \beta[vQ - C(Q) - QG(z_1) - x_* Q(1 - z_1)],$$

leading to the first-order conditions

$$(10) \quad \pi_{q_1}^{**} = 0 = v - C_1' - G_1 - x(1 - z_1);$$

$$(11) \quad \pi_{z_1}^{**} = 0 = -q_1 G_1' + xq_1 + \beta Q(x_* - G_1').$$

Equation (10) is equivalent to the results for the myopic case in equation (2), for fixed values of quality z_1. Comparing equations (9) and (10), it is clear that as the regulatory penalty is loosened from x to x_*, the incentive to expand output in period 2 is increased since the only terms that change will be the choice variable q_2 (through C_2') and the regulatory penalty per unit of output, which falls from $x(1 - z_1)$ to $x_*(1 - z_1)$.

Rewriting equation (11) in terms of the marginal investment cost yields

$$(12) \quad G_1' = (xq_1 + \beta x_* Q)/(q_1 + \beta Q) < x,$$

since $x_* < x$. Compared to the myopic quality choice in equation (3), the firm always underinvests in quality if the regulation will be loosened. This effect arises from a desire to prevent having overinvested in quality from the standpoint of the second period's regulatory policy in a situation in which investment decisions are irreversible.

[8] This result also implies that in the case of corner solutions in which the quality level is 1, there will be no effect of more stringent regulations on either the output or quality level since $1 - z$ equals zero once quality hits the maximum level.

Assuming the second-order conditions are fulfilled,[9] the effect of a relaxation of the regulatory policy can be summarized as follows:

$$\frac{\partial q_1}{\partial x_*} > 0; \quad \frac{\partial q_1}{\partial \beta} < 0; \quad \frac{\partial z_1}{\partial x_*} > 0; \quad \frac{\partial z_1}{\partial \beta} < 0.$$

Higher values of β, which reflect a greater weight on second-period decisions, depress both forms of investment. The x_* results differ from those for situations of increasing regulatory stringency since the second-period penalty affects z_1 as well as q_1. This difference arises because the firm no longer chooses z_1 myopically but must make a permanent quality investment commitment in period 1. This commitment is dependent on the penalty levels and capacity choices in both periods. Increases in the second-period x_* boost the quality commitment z_1. Unlike the situation of increasing regulatory stringency, there is no direct effect of x_* on q_1 since the irreversibility contraint on capacity investments is not binding, as the firm will increase its output in period 2. Since z_1 affects q_1, however, there is an indirect effect of x_* on q_1. The higher z_1 values induced by increases in x_* reduce the marginal regulatory penalties on output, so that increases in x_* also enhance the incentives for capacity investments.

The parallels with the situation of increasing regulatory stringency are clearer if one views these policies in terms of departures from the initial policy x. The more x_* is lowered below the initial penalty level, the more both q_1 and z_1 will be depressed. Similarly, the more x^* exceeds x, the greater will be the reduction in q_1. All shifts in regulatory policy depress the initial output level. In the case of increasingly stringent regulations, it is because firms underinvest to avoid an irreversible commitment to a level of production that will subsequently be inefficiently large; in the case of regulations being relaxed it is the feedback effect of reduced quality investments that diminishes output. Increasing the weight β on the second-period decisions always reduces both q_1 and z_1 when there is a shift in regulatory policies.

One might have expected that a known regulatory policy change would have influenced only one of the two forms of irreversible investment since a change in x will only make one of the first-period irreversibility constraints binding. The actual impact is more pervasive due to the interdependence of the two types of investment when regulations are being relaxed.

[9]This requirement is that $C_1''[G_1''q_1 - \beta Q_{z_1}(x_* - G_1') + \beta G_1''Q] - (G_1' - x)^2 > 0$, where $Q_{z_1} = (x_* - G_1')/C_2''$.

III. Uncertain Regulatory Policies

While industries occasionally face a known schedule of regulatory changes, particularly when very stringent regulations are being phased in gradually, future shifts in the regulatory policy are usually not specified in advance. This uncertainty is particularly great for regulations of hazards for which the available medical evidence is imprecise. The uncertainty regarding policy shifts, for any particular set of information, compounds these scientific uncertainties. If one assumes that firms are risk neutral, one might expect that the role of uncertainty could be treated using the results of Section II. After calculating the expected penalty $\bar{x}$ in period 2 and noting whether or not it involved a decrease or an increase in regulatory stringency, one might then apply the pertinent model for known regulatory changes. As the subsequent results will indicate, such a relationship does not hold, as regulatory uncertainties introduce new complications into the firm's decisions and the policy design process.

A. *Implications for Firms' Decisions*

Suppose the firm is facing a binary policy lottery in period 2, where the penalty may rise to x^* or fall to x_*, where $x^* > x > x_*$. The situation in which one of the second-period penalties equals x poses no additional complications for the analysis below, but for concreteness I will assume that the strict inequalities hold. If both x^* and x_* equalled x, the analysis would be the same as in Section II. The firm assesses the probability that x^* will be the penalty as p and the probability that x_* will be the penalty as $(1-p)$, and based on these expectations it is assumed to maximize discounted expected profits π.[10]

The decision in period 2 parallels the results for the situation of certain policy changes. If x rises to x^*, there will be no change in the output level since the firm cannot reduce output below its first-period level. The firm will, however, raise its quality investment z_2, which is given by $Z(x^*)$ and is defined by equation (5) as before. Similarly, reductions in x to x_* lead the firm to make no change in its quality investment but provide an incentive to raise output to $Q(x_*, z_1)$, which is implicitly defined by equation (9). From the standpoint of the second-period decisions, the uncertainty only affects q_2 indirectly through its effect on z_1.

The first-period problem for the profit-maximizing firm is a variant on the earlier problems for the certainty case since the firm will

$$\begin{aligned}\max_{q_1, z_1} \pi = {} & vq_1 - C(q_1) - q_1 G(z_1) - xq_1(1-z_1)\\ & + \beta p\left[vq_1 - C(q_1) - q_1 G(Z) - x^* q_1(1-Z)\right]\\ & + \beta(1-p)\left[vQ - C(Q) - QG(z_1)\right.\\ & \left. \qquad - x_* Q(1-z_1)\right],\end{aligned}$$

producing the first-order conditions

$$\begin{aligned}(13)\quad \pi_{q_1} = 0 = {} & v - C_1' - G_1 - x(1-z_1)\\ & + \beta p\left[v - C_1' - G_2 - x^*(1-Z)\right];\end{aligned}$$

$$\begin{aligned}(14)\quad \pi_{z_1} = 0 = {} & -q_1 G_1' + xq_1\\ & + \beta(1-p)\left[Q(-G_1' + x_*)\right].\end{aligned}$$

These conditions can be rewritten as

$$(15)\quad C_1' = v - \frac{G_1 + x(1-z_1) + \beta p G_2 + \beta p x^*(1-Z)}{1+\beta p};$$

$$(16)^{11}\quad G_1' = \frac{xq_1 + \beta(1-p)x_* Q}{q_1 + \beta(1-p)Q} > x_*.$$

Unlike the results for the certainty situation, neither of the first-period decisions takes the same form as with reversible investment decisions. Uncertainty affects both first-period decisions and does not hinge on the expected penalty $\bar{x}$. Rather, the choice of output q_1, which will be increased if x decreases and will remain the same if x rises to x^*, is not directly affected by x_*, but it is dependent on x^*. The reason for this asymmetry is that the irreversibility constraint will only be binding if x^* is the penalty so that only in this situation will q_1 be the output level. As indicated by equation (15), the firm equates the marginal production cost with the price less the conditional expected costs associated with low quality, where this expectation is restricted to the states in which q_1 is the output level. Equation (7) for the case of a certain increase in regulatory stringency is simply a special case of equation (15), where the value of p equals one.

The quality choice z_1 also is affected by a conditional expectation, but here the firm sets the marginal cost of quality investments equal to the expected penalties weighted by the output levels, the probabilities, and the discount factor. Equation (16) represents a generalization of equation (12) for the case of decreasing regulatory stringency. It is not the expected penalty $\bar{x}$ that influences decisions since the only second-period penalty value that enters is x_*. The value of x^* is irrelevant since a tighter penalty will lead the firm to augment its initial quality investment, so that the first-period quality commitment will no longer be a binding constraint. With irreversibilities, the focus should not be on the expected penalties, but on the level of the regulatory policy in states in which the irreversibility constraint is binding.

Equations (15) and (16) have unambiguous implications regarding the effect of future regulatory policy lotteries. Consider first the level of z_1 when compared to the revers-

[10]The introduction of risk aversion would reinforce the nature of the findings below by creating additional incentives for underinvestment.

[11]As in the certainty case, I assume that the second-order conditions are also fulfilled.

ible case. With myopic quality investments, the firm equates G' with x, but in the presence of regulatory uncertainty, the marginal cost of quality investments is equated to the expression on the right side of equation (16), which is clearly less than x. If there is any nonzero probability that the penalty will be relaxed, firms facing regulatory uncertainty will underinvest in quality when compared with the myopic case.

Uncertain regulatory policies will also lead to lower values of initial output if the right-hand side of equation (15) is below that in equation (2), a requirement that reduces to

$$(17)\quad [G_1 + x(1-z_1)] + \beta p[G_2 + x'(1-Z)] > [G + x(1-z)] + \beta p[G + x(1-z)].$$

In the myopic case, the optimal z minimizes $G + x(1-z)$, so that any effect of uncertainty on the z_1 selected will raise these quality-related costs in period 1. Except when $1-p$ equals zero (see equation (16)), there is always a distortion of the choice of z_1. The first bracketed term on the left-hand side of equation (17) will exceed its counterpart on the right-hand side, except when p equals 1, in which case the two terms are equal. From equation (8) above we know that the second bracketed term on the left-hand side of equation (17) exceeds the final term on the right-hand side except when there is no chance of a price increase (i.e., when $p = 0$). Uncertain regulatory policies will depress output provided *either* there is a nonzero chance of a penalty increase or a nonzero chance of a penalty decrease. Any nontrivial regulatory policy lottery will depress output.

Greater weight on the second-period outcomes in which the policy lottery occurs also have an adverse effect. Increasing the value of β has an unambiguous effect on q_1 and z_1. Total differentiation of equations (13) and (14) produces the result that $\partial q_1/\partial\beta < 0$ and $\partial z_1/\partial\beta < 0$, or greater weights on the period with uncertain regulatory policies will depress both types of investment in period 1.

Assessing the effects of changes in the lottery structure are more complicated since there are conflicting influences due to the complex interrelationships between q_1 and z_1. The direct effects of p on these variables are clear cut and, for the remainder of the paper, I will assume that these direct impacts are dominant.[12] Equivalently, I will focus on the effects of q_1 for fixed values of z_1, which upon differentiation of equation (13) yield

$$(18)\quad \frac{\partial q_1}{\partial p} = \frac{p[v - C_1' - G_2 - x^*(1-Z)]}{C_1''} < 0.$$

This expression is negative since, as was shown in Section III.A, the unit cost of low quality $G(Z) + x^*(1-Z)$ is an increasing function of x^*. Since the sum of the first- and second-period terms in equation (13) is zero, and since these quality-related terms represent the only difference between the two expressions, increasing q_1 must have a negative effect on the marginal profits resulting in the second period. If this were not the case, the irreversibility constraint would not be binding since additional profits would be yielded by increasing output in period 2 when the penalty rose to x^*.

The probability p of a penalty increase also has an unambiguous direct effect on z_1, for fixed values of q_1, since

$$(19)\quad \frac{\partial z_1}{\partial p} = \frac{\beta Q(-G_1' + x_*)}{\pi_{z_1 z_1}} > 0$$

(since G_1' exceeds x_*, see equation (16)). Increasing the chance of an increase in the regulatory penalty dampens the initial output level and raises the initial quality investment. These results always hold if there is only one choice variable, or in situations in which there are competing effects, if the direct effects are dominant.

[12]For example, in the case of $\partial q_1/\partial p$ the value obtained when effects through both choice variables are considered is negative except for the presence of a term $\beta Q(-G' + x)(G' - x_*)$ generated by the indirect effect of p on q_1 through z_1 that is positive since, from equation (16), we have $x > G_1' > x_*$. The underinvestment in quality increases the expected regulatory penalties on capacity investments, leading to a possible reversal in the $\partial q_1/\partial p$ result if this effect is large.

B. *The Effect on Profits and the Value of Information*

Since regulatory uncertainty alters enterprise decisions in a manner that is quite different from what would result if penalties in each period were equated to their expected levels, profits will also be affected. If the regulatory penalty x fully reflects the value of the quality component to society, the value of profits will equal the net surplus to society and can serve as an economic efficiency measure. To analyze the implications for firms' profitability, let us introduce the notation $\hat{\pi}$ to denote the present value of π obtained over both periods when the firm selects its choice variables optimally. The analogous values in period 2 will be $\hat{\pi}_2(x^*)$ for second-period profits if x^* is the penalty and $\hat{\pi}_2(x_*)$ after the penalty lottery has resulted in x_*.

The value of $\hat{\pi}$ depends on p directly and through its influence on the choice variables $q_1(p)$ and $z_1(p)$, which in turn affects $Q(x_*, z_1)$. When differentiating $\hat{\pi}$ with respect to p, all terms involving $\partial q_1/\partial p$ and $\partial z_1/\partial p$ will drop out (by the envelope theorem) since the investment levels will be chosen optimally in response to changes in any parameter such as p. The effect of p on profits is consequently given by

$$\partial\hat{\pi}/\partial p = \beta\left[\hat{\pi}_2(x^*) - \hat{\pi}_2(x_*)\right] < 0,$$

since profits are lower in the state with a higher regulatory penalty (i.e., $\hat{\pi}_2(x^*)$ is below $\hat{\pi}_2(x_*)$). Increasing the chance that the regulatory penalty will rise reduces the discounted expected profits, as one might expect. The second derivative of the profit function indicates the curvature of this relationship, where

$$\partial^2\hat{\pi}/\partial p^2 = \beta(\partial q_1/\partial p)\left[v - C_1' - G_2 - x^*(1-Z)\right] + \beta\frac{\partial_{z_1}}{\partial p}Q(G_1' - x_*) > 0,$$

which implies that $\hat{\pi}(p)$ is convex.[13]

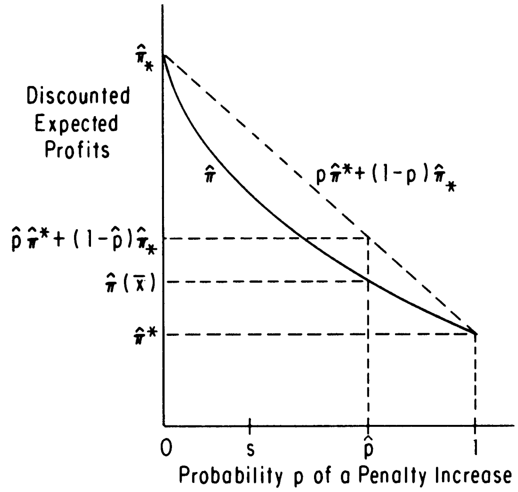

FIGURE 1. THE EFFECT OF REGULATORY UNCERTAINTY ON PROFITS

The function $\hat{\pi}$ is sketched in Figure 1. The two endpoints of the curve are the profits $\hat{\pi}_*$ with a certain drop in the penalty to x_* and the profits $\hat{\pi}^*$ with a certain increase in the penalty. The weighted average of these points is the dashed line that lies above the $\hat{\pi}$ curve. From Jensen's Inequality, we have the result that $p\hat{\pi}^* + (1-p)\hat{\pi}_*$ exceeds $\hat{\pi}(\bar{x})$, where these values are indicated on the diagram for one possible value of p, denoted by $\hat{p}$. The firm facing an uncertain regulatory policy lottery $(p, x^*; 1-p, x_*)$ will make lower profits than if it faced the penalty $px^* + (1-p)x_*$ with certainty.

A related issue is how the size of this loss is affected by the value of p. In particular, what is the expected value of perfect information *EVPI* regarding the future regulatory policy or, viewed somewhat differently, what is the minimal value of the expected opportunity loss that will be incurred? The *EVPI* value is simply the gap between the two curves in Figure 1, or

$$EVPI = p\hat{\pi}^* + (1-p)\hat{\pi}_* - \hat{\pi}.$$

[13] The direction of this inequality can be easily verified. As noted above, the value of the derivative of second-period profits with respect to q_1 is negative since the irreversibility constraint is binding so the bracketed term is negative. From equation (16), G' exceeds x_*, and the signs of $\partial q_1/\partial p$ and $\partial z_1/\partial p$ are negative and positive, respectively, assuming the direct effects of p are dominant.

The gap will reach its widest amount at some interior value of p. The effect of p on $EVPI$ is given by

$$\partial EVPI/\partial p = (\hat{\pi}^* - \hat{\pi}_*) - \partial\hat{\pi}/\partial p.$$

For small values of p, this expression is positive since the slope of the profit function $\hat{\pi}$ is steeper than the weighted average curve. The losses due to uncertainty are greatest when $\partial\hat{\pi}/\partial p$ equals $(\pi^* - \pi_*)$, which is the slope of the weighted average curve, and $EVPI$ decreases thereafter. The point s in Figure 1 represents the p value at which maximum efficiency losses occur; s need only be some interior point and is not necessarily $1/2$.

One would expect that a firm's profits would be decreasing with respect to p wholly apart from any losses from uncertainty since higher regulatory penalties increase its costs. The more interesting result is that uncertain regulatory policies impose additional opportunity losses as firms are discouraged from making irreversible investment commitments. These losses are greatest when the lottery on regulatory penalties involves an intermediate p value rather than an extreme probability close to zero or one.

IV. Conclusion

Three separate effects of regulatory policies on enterprise decisions can be distinguished. First, increased regulatory penalties will diminish output and profits in static models or, equivalently, in multiperiod models in which investments are completely reversible, as is well known. Second, if investment commitments are irreversible, there will be an additional effect of a known schedule of changes in the regulatory policy, which will depress output even further. Finally, the addition of uncertainty with regard to regulatory policy produces a third effect resulting in expected opportunity losses for firms. Both output and quality investments will be depressed by regulatory policy lotteries. Regulations influence current enterprise decisions not only through their current level, but through their expected future level and the degree of uncertainty regarding these future regulatory policies.

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