PWP-022

REGULATING BYPASS

Matthew W. White

August 1994

Abstract

This paper examines optimal regulatory response to a utility customer considering service from an alternate, unregulated supplier. The bypass of utility service may be costly to a regulator concerned with the allocation of a utility's revenues among consumers. This paper presents a theoretical analysis of how a regulatory agency should respond to a bypass threat from a customer considering exit. In contrast to existing practices, this analysis explicitly accounts for the incentive effects arising when the regulator is uncertain about the customer's cost of alternate supply. Under mild regularity conditions, we derive an explicit bypass policy as a function of the regulator's assessment of the potential bypasser's willingness to pay for utility service, and prove the optimality of this policy given the regulator's limited information. This optimal policy involves setting a price equal to the utility's marginal cost of service, and then requiring the customer to pay a fixed charge reflecting the likelihood of bypass. In addition, we demonstrate that even under an optimal bypass policy there is an inefficiently high likelihood of bypass relative to a full-information environment. We address some limitations of current regulatory practice in light of these findings, with particular regard to the electric power and telecommunications industries.

About the Author

Matthew W. White is a Ph.D. Candidate in the Department of Economics, University of California, Berkeley. The author thanks Richard J. Gilbert, Benjamin E. Hermalin, and Michael H. Riordan for helpful comments and discussions. Financial support provided by the University of California Energy Institute.

Address for Correspondence

Energy Institute
University of California
Berkeley, CA 94720-5180

Phone: 510-642-9588
Fax: 510-643-5180
Email: mwwhite@econ.berkeley.edu

1. Introduction

In debates surrounding the restructuring of industries traditionally accorded "natural monopoly" status, competitive entry has been promoted as an effective means of achieving a more efficient market structure. This paper is concerned with a particular form of competitive entry known as *bypass*. Bypass occurs when a customer of a regulated monopoly chooses to forego utility service in favor of acquiring services from an alternate, unregulated supplier, or providing services to itself. The bypass phenomenon is most acute in the telecommunications and electric power industries, where innovation in small scale technologies and the historical pattern of average-cost pricing have given large customers feasible alternate supply options. To a lesser extent, bypass has arisen with the introduction of competition into other traditionally regulated industries, notably satellite and cable television transmission, postal services, and natural gas transmission and distribution.

Bypass is most appealing to consumers whose large and stable demand characteristics allow them to exploit economies of scale on a stand-alone basis.[1] These demand characteristics also make them a utility's most valuable customers. In many cases, the exiting customers face rates that contribute substantial revenues toward the fixed cost of utility services. In the case of telecommunications, for example, part of the toll usage price paid by large consumers of a local telephone company's services subsidized the cost of single-line customer access.[2] Hence, even when unregulated suppliers cannot provide a more efficient technology, they can often provide a lower-cost bundle of services to a high-demand consumer.

The bypass phenomenon presents regulators with a predicament involving both efficiency and distributional concerns. Not surprisingly, the issue generates substantial controversy in the current regulatory arena.[3] Advocates of limiting the entry of competitive providers (or the exit of consumers to

---

[1]Examples include: In electric power, large industrial manufacturers that choose to self-provide through a cogeneration technology supplying both thermal energy and electrical power; in telecommunications, large businesses that contract with an independent provider of switching services for connection to a long-distance carrier; and in natural gas markets, high-volume customers that contract directly for wholesale gas and interstate pipeline capacity, thereby avoiding gas procurement from the local distribution company.

[2]Einhorn (1987).

[3]See especially the proceedings before the California Public Utilities Commission regarding its April 1994 proposal for direct customer access to private utilities' electric transmission networks ("retail wheeling") in California (CPUC (1994)). Similar cases are before the commissions of Connecticut and Michigan.

self-provision technologies) argue that bypass wastefully duplicates the utility's existing capacity, adversely affects capacity utilization, and complicates investment planning of regulated firms which are obligated to serve.[4] The most strident argument presented against bypass is based on equity, however; after a large customer exits, the rates of the consumers remaining on the utility's system must rise because the burden of fixed cost recovery falls upon a reduced consumer base.

Others have argued that, to the contrary, the advent of bypass and regulators' inability to prevent bypass by decree constitutes competitive incentives and improves total welfare. Such arguments address inefficiency on the part of both the monopoly and the regulatory agency. In particular, the threat of bypass effectively functions as the entry of a competitive fringe whose presence, to the benefit of consumers, may promote efficiency on the part of the incumbent monopoly.[5] Bypass can provide a check on inefficient regulatory behavior as well, limiting the ability of regulators to depart from marginal-cost pricing. For example, the potential for bypass undermines possible cross-subsidization of residential POTS ("plain-old telephone service") consumers by large commercial and industrial firms. Moreover, it is clear that in some cases bypass is efficient independent of the incumbent utility's response. In electric power, for example, the total costs of self-provision are sometimes less than the utility's incremental cost of serving the same demand, even when the utility faces excess capacity.[6] Hence, policies that attempt to encourage or to deter bypass represent more than just different ways of slicing an existing social-surplus pie.

Regulatory reactions to bypass challenges have been varied, but generally share a common goal. Most commissions have instituted policies designed to limit what is considered "uneconomic bypass", when there is no cost advantage to bypass vis-a-vis the utility's incremental cost. In this vein, the California Public Utilities Commission has held that a utility may meet a "credible" bypass threat with a special rate schedule having as a floor the utility's incremental cost. Establishing credibility as a potential bypasser, however, at times appears to require little more than the filing of a request for special rates.[7] Such policies give consumers with uneconomic bypass options incentives for rent-seeking behavior, resulting in unnecessary and socially costly rate restructuring.

---

[4]Marnay (1989).
[5]Caillaud (1990).
[6]Rose and McDonald (1981)
[7]Marnay (1989)

Despite the regulatory controversy surrounding the bypass problem, there has been little normative analysis of bypass in the context of the rate-of-return or cost-of-service regulatory framework practiced by most state utility commissions. Laffont and Tirole (1990) examine how to regulate a monopoly when bypass introduces constraints on an optimal incentive-regulation scheme. Under the important assumptions that bypassers and captive consumers are (ex ante) indistinguishable and that the cost of bypass is fixed and observable, Laffont and Tirole show that it may be optimal to price below marginal cost to retain a potential bypasser and that there is excessive bypass if the regulator cannot control exit. In contrast, Einhorn (1987) finds that customers can be induced to make only efficient bypass decisions. He shows, in a full-information setting, that inducing these efficient choices may require optimal prices to fall below their associated marginal costs of service. Other questions, regarding the use of entry as a regulation mechanism, are investigated in Demski, Sappington, and Spiller (1987) in the context of supplier switching. Caillaud (1990) addresses the use of a competitive fringe to discipline a regulated firm via correlation between the unknown costs of the fringe and those of the regulated firm.

This paper investigates a regulator's optimal response to a bypass threat when the regulator has imperfect information regarding the customer's willingness to pay. In contrast to the existing literature, bypass typically occurs in a traditional rate-of-return regulatory environment in which the dominant uncertainty confronting regulators is the bypasser's reservation price, not the utility's incremental cost of service. This paper pursues an analysis of bypass in such an environment. In addition, this paper illustrates the limitations of current regulatory policies regarding bypass. By way of deriving an optimal bypass policy, the ramifications of private information with respect to alternate supply options are addressed, as is the social cost of policies which do not take this asymmetry into account.

2. The Bypass Problem: A Simple Illustration

A successful regulatory policy must acknowledge the informational asymmetry between the regulator and the potential bypasser. The characteristics of an optimal policy that acknowledges this asymmetry will be taken up in the following sections. However, the problem posed by private information can be shown with a simple illustration.

Consider a regulated monopolist producing a commodity at a constant marginal cost, m, after incurring a sunk cost. The monopolist sells x_1 units to a downstream firm for revenues $R(x_1) > mx_1$, and x_2 units to the remaining consumers.

Now suppose the downstream firm reports an alternative method of supply at an observable constant cost c. Clearly, from a social efficiency standpoint this firm should bypass the utility only if $c \leq m$. In fact, typical regulatory practice is to accept a new price schedule whenever the new revenues are no less than mx_1. The resulting "anti-bypass" rates therefore deter exit only if bypass is economically inefficient.

The caveat to this analysis is the assumption of *observability* of alternate supply costs. It is implausible that contract negotiations for alternate supply are observable by parties other than the potential bypasser and supplier. As argued by Katz (1991), contracts are private arrangements between parties, and in this context unobservable (ex ante, if not ex post) by the regulatory agency or utility. Furthermore, both parties to a bypass contract will likely have strong incentives to keep contract details private, as observable contracts may hinder the buyer's ability to negotiate low-cost utility supply and the seller's prospects for future sales.

With unobservable contracts and private information, the strategy of truthfully revealing bypass costs is dominated (for high-cost bypassers) given the regulatory policy above. A firm can do at least as well by claiming to have unit costs of m than by truthfully revealing cost c. If $c \leq m$, the firm bypasses; if $c > m$, the firm gains at least $R(x_1)-mx_1$, which is strictly positive.[8]

Under a rate-of-return regulatory framework, to continue to satisfy the utility's participation constraint, the regulator must reallocate the lost revenues from the bypass or the anti-bypass rate policy to the remaining customers. This leads to the issue of equity and the regulator's distributional concerns. From the perspective of a regulator concerned with maximizing a welfare function weighted toward the captive consumers, the anti-bypass rates involve an explicit welfare loss.

As a result, the regulator's problem is to devise a policy which minimizes the welfare loss of bypass given the private information possessed by the potential bypasser. As in Baron and Myerson (1982) and Guesnerie and Laffont (1984), the regulator's problem can be viewed as a Bayesian game in

---

[8]If the revenue function $R(\cdot)$ initially specifies a price greater than m, the firm's gain from claiming bypass cost $\hat{c}=m$ will strictly exceed $R(x_1)-mx_1$ whenever the firm's demand is less than perfectly inelastic.

which the regulator chooses an optimal policy given its beliefs, and the firm chooses a best reply to the regulator's policy given its private information. By the revelation principle, the regulator can be restricted to providing a direct-revelation mechanism in which the firm's strategy is to report it's cost, or *type*, truthfully. Within this set of mechanisms, the regulator's problem is to devise a set of policies which maximize welfare and induce the firm to truthfully reveal its type.

The example illustrated above also reveals some of the complications that arise in models of bypass. The first is that, unlike the "standard" moral-hazard principal-agent framework (see Baron (1989)), here the reservation utility of the agent is not independent of the agent's type. In fact, it is critical to the problem at hand that the optimal policy satisfy a set of individual rationality constraints which vary continuously across the spectrum of potential bypassers. As noted by Fudenberg and Tirole (1991, p. 263), there are no general results for such models. For example, the standard result that the participation constraint binds only "at the bottom" (i.e., for only the most inefficient type) will not necessarily hold, and in particular, does not hold for the problem presented in this paper.

A second complicating factor is that the supplier-switching phenomenon considered here gives rise to non-differentiable incentive compatibility constraints. If a firm misrepresents its cost, it may receive a different price, but it still retains the option to bypass at the true bypass cost. To deter bypass, a policy must give the firm a greater return than the payoff from the minimum of its true bypass cost and the offer induced by a different cost representation. This minimum value function inherent in models of bypass leads to discontinuities in the regulator's control problem. This complication is mitigated in our model by expanding the regulator's choice set, a modeling approach inspired by Myerson (1979).

3. The Model: Basic Structures

Consider a firm initially purchasing x units of a factor from a franchise monopoly. The firm subsequently learns of an alternate supply option available at unit cost c, a random variable drawn from an interval of $\mathbb{R}$. The technology available to the incumbent monopoly yields production at (observable) marginal cost m and fixed cost K, an assumption of global increasing returns to scale.[9] The monopoly

[9]The critical cost assumption here is only that the monopoly cannot break even under marginal-cost pricing.

meets all demand at regulated prices as long as its profit exceeds some (commonly known) reservation level, and is therefore not a strategic player.[10,11]

In addition to the firm's initial consumption, x, there is a set of atomistic individuals receiving surplus CS from consumption of x_c units of the utility's output. It is assumed that bypass is either uneconomic or technologically infeasible for this set of agents (the "captive" customers), who will simply be referred to as *the consumers*.

The regulator is posited to maximize expected social welfare subject to its preferences over the distribution of income. We represent this welfare function as a weighted sum of consumer and producer surplus:

$$W = \mathrm{E}\{\alpha\Pi + CS + \lambda\Psi\} \tag{1}$$

where Ψ is the profit of the utility, CS is the consumers' surplus, Π is the downstream firm's profit, and E is the expectation operator. The parameters α and λ are fixed weights reflecting the regulator's preferences over income distribution. We presume that $\alpha, \lambda \in (0,1)$, implying a preference for the allocation of social surplus to the captive consumers. This allows us to simplify the regulator's problem when the downstream firm has an unknown reservation level: The regulator will always find it optimal to give the utility just enough profit to leave it indifferent to participating in the market. Without loss of generality, we normalize the utility's reservation profit to zero.

The timing and overall information structure of the bypass game are as follows:

Stage 0: Under the regulator's initial revenue allocation, the firm and the consumers each pay a positive share of the utility's fixed cost of production.

Stage 1: The firm learns its type, θ, which is its private information. It then requests (and is offered) a policy, $M(\theta)$, from the regulator.

Stage 2: The firm chooses an anti-bypass or bypass-inducing rate schedule $M(\hat{\theta})$ by means of announcing a type, $\hat{\theta}$, takes the corresponding action, and receives the associated payoff.

---

[10]Except for the binary shutdown decision.

[11]To avoid further ambiguity in exposition, hereafter *the firm* denotes the downstream firm contemplating bypass, and *the utility* specifies the regulated monopolist initially producing the commodity of interest.

Let us be more precise in defining the firm's type. Rather than specifying the downstream firm's type in terms of the unit cost c, we define the firm's type as its *opportunity cost* of *not bypassing* the utility. To maintain consistency with the example of the preceding section, define the firm's type, θ, by

$$\theta \equiv \max_{x \in \mathbf{R}_+} B(x) - cx \tag{2}$$

where, denoting $\mathbf{R}_+ \equiv [0,\infty)$, $B: \mathbf{R}_+ \to \mathbf{R}_+$ continuously differentiable with $B(0) = 0$ and $B' > 0$, $B'' < 0$ $\forall\, x > 0$. The value function $B(x)$ can be interpreted as a production function concentrated with respect to factor x, that is, of form $\tilde{B}(x, y^*(x))$, where y^* is the vector of all other input factors chosen optimally given x. The concavity of B is not important in the sense of requiring decreasing returns to scale; it merely allows us to ensure a unique finite solution to the firm's problem without introducing assumptions regarding the market for the downstream firm's output.[12]

Similarly, if the firm chooses to remain on the utility's system at a regulated price p, it receives benefits

$$U(p(\hat{\theta})) \equiv \max_{x \in \mathbf{R}_+} B(x) - p(\hat{\theta})x \tag{3}$$

where $\hat{\theta}$ is the report the firm makes to the regulator. The function U represents the firm's payoff, gross of any transfers, from taking an anti-bypass price p offered in response to a bypass threat $\hat{\theta}$. Note that a high-θ type is an *efficient* bypasser, and a low-θ type is an *inefficient* bypasser.

Viewing the bypass option in terms of opportunity cost provides a more general framework than basing a model on the direct cost, c. In particular, it renders the assumption that bypass occurs with constant marginal and average cost trivial, since the cost cx in (2) is readily generalized to a function $C(x)$ to incorporate nonlinear bypass costs.[13] Such a generalization is not so transparent in the framework of Section 2, where a nonlinear bypass cost exacerbates the discontinuity problem arising under

---

[12]Since in this model the downstream firm is effectively a consumer, an alternative way to view $B(x)$ is as a money metric utility function over x given fixed prices c. In this case, the derivative restrictions correspond to the standard assumption of diminishing marginal utility.

[13]As a practical matter, bypass in both telecommunications and energy is usually characterized by a high access fee or setup cost, and a relatively low cost per unit consumed. These sharply increasing returns to scale in the alternate technology are what drives the assumption that bypass is never economic for "small" customers, given the presence of coordination failures, transaction costs, and spatial heterogeneity among consumers.

incentive compatibility.

The cost of this generality is an additional assumption over the regulator's beliefs. With a Bayesian game, the regulator is considered to have a prior belief given by a probability measure over the set of possible types. We will take the regulator's primitive to be the opportunity cost θ, not the direct cost of bypass, $C(\bullet)$; that is, rather than posit that the regulator calculates a prior on $C(\bullet)$, we assume the regulator is endowed with a prior F over the scalar opportunity cost $\theta \in \Theta$.[14] The prior distribution function, $F(\theta)$, is assumed to be absolutely continuous with density function $f(\theta) > 0$ on a non-empty set $\Theta = [\underline{\theta}, \bar{\theta}] \subset \mathbf{R}_+$.[15]

The regulator's ability to deter bypass is limited to incentive mechanisms; that is, bypass cannot be controlled *per se*. Within this framework, however, we wish to give the regulator a broad set of tools with which to achieve its objective. To induce firms either to bypass or to remain on the utility's system, the regulator can offer both a price and a transfer to the firm. In addition to subsidies to retain a potential bypasser, we allow negative transfers representing a tax on the firm. Since we seek a balanced mechanism, any transfer to the firm must be paid for by the consumers.[16]

In addition, we allow the regulator to choose a probability of continuing to serve a potential bypasser. Although the regulator cannot directly prevent a firm from leaving the system, it can choose whether to continue utility service. For a firm with a sufficiently high opportunity cost, bypass will be efficient from a social perspective since deterring high-θ types would require too great a transfer from consumers. Since the firm's surplus is a component of the regulator's welfare function, in equilibrium a firm will be "refused a price" if and only if an offered price would still induce bypass; that is, when the regulator prefers that type to leave the system. We interpret the probability function as a decision rule with which the regulator chooses not to deter bypass with rate schedule $\{p,t\}$.

---

[14]Note that, even if the value function $B(\bullet)$ is common knowledge, the measurable transformation $C(\bullet) \mapsto \theta$ generalizing (2) is onto and thus entails some loss of information. Analysis of the direct cost of bypass generalized from c to $C(\bullet)$ would require specification of a prior probability distribution over functions as opposed to intervals, however, complicating our exposition; hence we address a prior over the scalar θ.

[15]Since $B(0)=0$, the set of possible opportunity costs is bounded below by zero; the other assumptions following (2) ensure that the firm has a finite opportunity cost. Consequently, Θ is bounded above and below; moreover, the concavity of (2) and the assumption that c is drawn from an interval ensure that there exist constants $\underline{\theta}, \bar{\theta} \in \mathbf{R}$ such that $\Theta = [\underline{\theta}, \bar{\theta}]$, endpoints possibly excepted.

[16]Otherwise the utility's participation constraint would be violated.

DEFINITION 1: *A regulatory policy* $M = \{p(\theta), t(\theta), z(\theta)\}$ *consists of three instruments: a price function* $p:\Theta \to \mathbf{R}_+$, *a transfer* $t:\Theta \to \mathbf{R}$, *and a probabilistic decision rule* $z:\Theta \to [0,1]$.

It is the probability instrument of the regulator that allows us to address, in a tractable manner, the potential discontinuities inherent in the bypass problem. More precisely, a model based on the direct cost of bypass, c, leads to incentive compatibility constraints of the form:

$$c \in \underset{\hat{c}}{\operatorname{argmax}} \left[B(x(\min\{p(\hat{c}),c\})) - x(\min\{p(\hat{c}),c\})\cdot\min\{p(\hat{c}),c\} \right], \tag{4}$$

In contrast, by letting the regulator choose a probability, 1-$z(\theta)$, with which to "deter" bypass, the firm's incentive constraints are a convex combination of the payoff in each of two states, corresponding to whether bypass occurs or not. Denote by $\pi(\hat{\theta}(\theta);\theta)$ a type θ firm's expected profit from strategy $\hat{\theta}$. The firm's problem is to choose a map $\hat{\theta}:\Theta \to \Theta$ which maximizes expected profit given the regulator's policy, *M*:

$$\max_{\hat{\theta}(\bullet)} \pi(\hat{\theta}(\bullet);\theta) \equiv z(\hat{\theta})\cdot\theta + [1-z(\hat{\theta})]\cdot U(p(\hat{\theta})) + t(\hat{\theta}) \tag{5}$$

The corresponding incentive compatibility constraint is therefore simply

$$\theta \in \underset{\hat{\theta}}{argmax} \;\; \pi(\hat{\theta};\theta) \quad \forall\, \theta \in \Theta \tag{6}$$

where the policy instruments $\{p(\theta),t(\theta),z(\theta)\}$ have been chosen by the regulator. This brings us to the issue of *implementability*.

DEFINITION 2: *A decision rule* $z:\Theta \to [0,1]$ *is* implementable *if there exist corresponding instruments* $p:\Theta \to \mathbf{R}_+$ *and* $t:\Theta \to \mathbf{R}$ *such that (6) is satisfied.*

A mechanism is considered implementable if the supporting decision rule is implementable. Ultimately, the space of feasible regulatory policies is restricted to the set of implementable mechanisms, a point to which we will return in Section 4.

Because the event in which bypass occurs may involve a redistribution of surplus, consumers are not indifferent to the regulator's bypass policy. As a reference point, let the value to consumers of the utility's service if only the captive customers remain on the system be denoted by v. Consumers value the commodity sufficiently that it is never optimal to shut down the utility after a bypass, that is, under some revenue schedule $\tilde{R}$ where the utility at least breaks even the consumer (inverse) demand function $D(\bullet)$ is sufficient to make production Pareto superior to shutdown:[17]

$$v \equiv \max_{x} \int_{0}^{x} D(\omega)d\omega - \tilde{R}(x) > 0. \tag{7}$$

The assumption that the regulator chooses an efficient revenue schedule for the consumers after bypass is consistent with the regulator's preferences as reflected by optimization of (1).

Retaining a potential bypasser is in the interests of consumers insofar as some of the fixed cost of utility service can be borne by the downstream firm. In fact, under (1) the regulator prefers to distribute to consumers all surplus accruing from production of the commodity of interest. The value to consumers if a firm remains on the system is therefore v plus any rent appropriated from the firm by a regulatory policy in which the firm pays more than its marginal cost of service. Specifically, if a firm chooses to remain on the system at price $p(\hat{\theta})$, the value to consumers, gross of transfers, is $v + V(p(\hat{\theta}))$ where

$$V(p(\hat{\theta})) \equiv [\ p(\hat{\theta}) - m\ ]\, x^{*}(p(\hat{\theta})) \tag{8}$$

and $x^{*}(p(\hat{\theta}))$ is the firm's optimal choice of the input factor, that is, the solution to program (3).

Given this structure of consumer preferences, we can restate more precisely the objective of the regulator as maximization of expected welfare with respect to instruments $\{p(\theta),t(\theta),z(\theta)\}$:

$$\max W = \int_{\Theta} \{\ v + [1-z(\theta)]\, V(p(\theta)) - t(\theta) + \alpha\Pi(p(\theta),t(\theta),z(\theta)) + \lambda\Psi\ \}\ dF(\theta). \tag{9}$$

[17]Neglecting income effects.

4. An Optimal Bypass Policy: Solution and Analysis

By the revelation principle, we may limit attention to policies that give the firm no incentive to falsely report its type. A mechanism is considered *feasible* if it is implementable and satisfies the firm's participation constraint:[18]

$$\pi(\hat{\theta}(\theta);\theta) \geq \theta \tag{10}$$

Let a type-θ firm's profit under truthful revelation be denoted $\Pi(\theta) \equiv \pi(\theta;\theta)$. Note that the utility's individual rationality constraint is always binding. Under the convenient normalization of the utility's reservation profit to zero, the Ψ term may be dropped from further analysis of (9).

LEMMA 1: *A feasible policy satisfies:*

(i) $$\frac{d\Pi(\theta)}{d\theta} = z(\theta) \quad \textit{almost everywhere} \tag{11}$$

(ii) $z(\theta)$ *non-decreasing in* θ.

Proof: By revealed preference; see Appendix.

Now from the expression in (5) and the definition of $\Pi(\theta)$, incentive compatibility implies

$$\Pi(\theta) = z(\theta)\,\theta + [1-z(\theta)]\,U(p(\theta)) + t(\theta) \tag{12}$$

which can be used to rewrite the regulator's objective function in (9) as

$$W = \int_{\Theta} \{ v + z(\theta)\,\theta + (1-z(\theta))[V(p(\theta)) + U(p(\theta))] - (1-\alpha)\Pi(\theta) \} \; dF(\theta) \tag{13}$$

Consider the last term in the above integrand. Since $z(\theta)$ is a probability, $0 \leq z(\theta) \leq 1$, so from (11) $\Pi(\theta)$ is non-decreasing in θ. Integrating (11) gives

[18] Note that (10) embodies the inability of the regulator to prevent bypass *per se*; it is *infeasible* for a regulator to impose a negative transfer (i.e., an exit fee) on a bypassing firm.

$$\Pi(\theta) = \Pi(\bar{\theta}) - \int_{\theta}^{\bar{\theta}} z(\omega)\, d\omega \, ; \qquad (14)$$

using (14) and integration by parts yields

$$\int_{\Theta} \Pi(\theta)\, dF(\theta) \;=\; \Pi(\bar{\theta}) - \int_{\Theta} F(\theta) z(\theta)\, d\theta \qquad (15)$$

and therefore:

$$W = \int_{\Theta} \left\{ v + z(\theta)\theta + (1-z(\theta))[V(p(\theta)) + U(p(\theta))] + (1-\alpha)\frac{F(\theta)}{F'(\theta)} z(\theta) \right\} dF(\theta) \;-\; (1-\alpha)\Pi(\bar{\theta}). \qquad (16)$$

Several remarks are in order. First, the incentive compatibility condition embodied in (12) and therefore in (16) is a local condition. It would be global if we were assured *a priori* that the maximand in (5) is concave, but no such prior appears justifiable. Lemma 2, however, gives us a sufficient condition.

LEMMA 2: *If $z(\theta)$ is non-decreasing, local incentive compatibility is sufficient for global incentive compatibility.*

Proof: See Appendix.

Second, the welfare function in (16) differs from that of standard models in two interesting respects. Since $0<\alpha<1$, W is decreasing in $\Pi(\bar{\theta})$ so it is optimal to set this participation constraint binding: $\Pi(\bar{\theta}) = \bar{\theta}$. Recall that $\bar{\theta}$ is the *most* efficient bypasser, so that the participation constraint binds for the *best* type. Third, note that the sign on the "information rent" term $(1-\alpha)[F(\theta)/F'(\theta)]$ in the welfare function (16) is positive, not negative. This suggests that firms may instead be subjected to an "information tax", a conclusion verified in Proposition 3.

By the use of Lemmas 1 and 2, we have reduced the regulator's problem to the maximization of (16) subject only to the monotonicity constraint in (*ii*) of Lemma 1, and the firm's individual rationality constraint (10).[19] Although the transfer function $t(\theta)$ has been eliminated from the objective function (16), it will be obtained from the requirement that the transfer policy uphold implementability. We will return to this in Proposition 3.

We are now in a position to state several results.

PROPOSITION 1: *Regardless of the regulator's prior, an optimal price to offer is marginal cost.*

Proof: Denoting the integrand in (16) by $h(p, z;\theta)$, observe that for $p > 0$

$$h_p(p,z;\theta) = \left([p(\theta)-m]\ \frac{dx^*}{dp} + x^*(p(\theta)) + \frac{dU}{dp}\right)(1-z(\theta)) \tag{17}$$

provided this derivative exists. Now, $U=U(x(p),p)$ but by the definition of U in (3) x is chosen optimally given $p(\theta)$ for all θ, so, by an application of the envelope theorem, $dU/dp = -x^*(p(\theta))\ \forall\ \theta\in\Theta$. Now since the program (3) has a unique solution, comparative statics on U at $x^*(p)$ imply that $dx^*/dp = 1/B''(x^*) < 0$ for $x^* > 0 \Leftarrow 0 < p < B'(0)$ by (3), and similarly that $dx^*/dp = 0$ for $p > B'(0)$. Hence, under continuity and concavity of $B(\bullet)$, the derivative $h_p(p, z;\theta)$ is well-defined on $0 < p < B'(0)$ and given by:

$$h_p(p,z;\theta) = \left(\frac{p(\theta)-m}{B''(x^*)}\right)(1-z(\theta)). \tag{18}$$

Note that for any (fixed) θ, $h_p(p, z;\theta)$ is zero for $p(\theta) > B'(0)$, has unequal left and right-hand derivatives at $p(\theta) = B'(0)$, and fails to exist if $p(\theta) = 0$ (the latter by inspection of $h(p, z;\theta)$ using (3) and (8)).

Now recall that before learning its type, the firm is initially operating with positive output at a price at least as great as m, so that $B'(0) > m$. Thus it suffices to consider only solutions p such that $p(\theta) < B'(0)$: Any $p \geq B'(0)$ on an F non-negligible subset of Θ is dominated (with respect to maximizing W) by $\tilde{p}$ where $\tilde{p} = p$ on $\{\theta \in \Theta : p(\theta) < B'(0)\}$ and $\tilde{p} = (B'(0) + m) / 2$ elsewhere on Θ. Thus we may restrict attention to the set of maps $\wp = \{p\colon \Theta \to (0, B'(0))\}$, which implies an interior solution $x^*(p)$ to (3) with probability 1.

[19]The individual rationality constraint (10) will be verified ex post.

Since $h(p, z;\theta)$ is continuously differentiable on $(\underline{\theta},\overline{\theta})\times(0,B'(0))$, by application of the Maximum Principle a (piecewise continuous) optimum p^* in $\wp$ satisfies

$$\left(\frac{p^*(\theta)-m}{B''(x^*(p^*(\theta)))}\right)(1-z^*(\theta)) = 0 \quad \forall\, \theta\in\Theta \tag{19}$$

where z^* is the optimal decision rule, i.e., $z^* \in \text{argmax}_{z\in Z}\, W(p^*, z)$ for admissible set $Z = \{z : \Theta \rightarrow [0,1]\}$. Define $\theta^*(z^*) = \sup\,\{\theta \in \Theta : z^*(\theta) < 1\}$ for any z^* not identically 1. Then the left-hand side of (19) vanishes for all $\theta \leq \theta^*$ if and only if $p^*(\theta) = m\ \forall\, \theta \leq \theta^*$. Furthermore, given that $z^*(\theta)$ is non-decreasing (from Lemma 1), $p^*(\theta)$ is arbitrary for $\theta > \theta^*$ by (19) and the definition of θ^*, so set $p^*(\theta) = m$ everywhere on Θ.

Finally, since $dx^*/dp < 0$ everywhere on $\wp$, $p^*(\theta) = m$ satisfies the Legendre condition

$$h_{pp}(p,z;\theta) = [p(\theta)-m]\,\frac{d^2x^*}{dp^2} + \frac{dx^*}{dp} < 0 \quad \forall\, \theta\in\Theta \tag{20}$$

so $p^*(\theta) = m$ is indeed optimal. Q.E.D.

The regulator's welfare maximization also minimizes quantity distortion in the firm's consumption decision, (3). Since the regulator has the ability to use non-linear pricing via the lump sum transfer t, it can appropriate any possible surplus from the firm without distorting the utility's production level away from the first best.

From an economist's perspective, Proposition 1's familiar marginal-cost pricing result is comforting in its consistency with established theory. It also suggests that the current bypass policy followed by the California Public Utility Commission and other regulatory agencies, while not optimal, is at least heading in the right direction.[20]

[20] It is also worth noting that Proposition 1 contrasts with results in Einhorn (1987) and Laffont and Tirole (1990). Laffont and Tirole find that it may be optimal to price *below* marginal cost under the assumption that the regulator's prior F is identical for all customers, in which case the regulator offers a low price and high fixed charge to separate the potential bypassers from the otherwise unidentifiable captive customers. Einhorn finds a similar high access fee, below marginal-cost price result in a full-information context when the regulator cannot use third-degree price discrimination.

Despite the premise of asymmetric information which motivates this paper, it is useful to consider the relation of the results to the case in which the regulator directly observes bypass costs. Under full information, the regulator can induce bypass if it is efficient and deter bypass if it is not, the *first-best* solution to the bypass problem.

PROPOSITION 2: *When agents have private information about the cost of bypass, the likelihood of bypass is too high relative to the first-best.*

A simple proof under the standard monotone hazard rate property (MHRP) follows; a proof of Proposition 2 for general F is provided in the appendix.

Proof: Differentiating $h(p, z; \theta)$ pointwise with respect to $z(\theta)$ yields

$$h_z(p,z;\theta) = \theta - V(p(\theta)) - U(p(\theta)) + (1-\alpha)\frac{F(\theta)}{F'(\theta)} \tag{21}$$

so the decision rule is degenerate: $z^*(\theta) \in \{0,1\}$ a.s. For purposes of maximizing $W(p, z)$ we may ignore maps on null sets and require $z^*(\theta) \in \{0,1\}$ for all θ.

Now by Proposition 1 and (8), $V(p(\theta)) = 0$ under the optimal policy. Since the firm is initially operating at a price no less than m (prior to learning its type), $B'(0) > m$ and therefore $U(m) > 0$. Under full information, the right hand side of (21) is θ - $U(m)$, so the first best decision rule is:

$$z^{FB}(\theta) = \begin{cases} 1 \ \text{if}\ \theta > \theta^{FB} \\ 0 \ \text{if}\ \theta \leq \theta^{FB} \end{cases} \tag{22}$$

where $\theta^{FB} \equiv U(m)$ defines the marginal type.

With private information, $(1-\alpha)F(\theta)/F'(\theta) \geq 0$ and strictly positive except at $\underline{\theta}$ since $0 < \alpha < 1$ and F continuous with $F' > 0$ on Θ. Now if F/F' is non-decreasing (the monotone hazard rate property), then there exists a unique value $\theta^* \in \Theta$ which solves

$$\theta^* + (1-\alpha)\frac{F(\theta^*)}{F'(\theta^*)} = U(m) \tag{23}$$

so the optimal decision rule under asymmetric information is:

$$z^*(\theta) = \begin{cases} 1 \text{ } if \text{ } \theta > \theta^* \\ 0 \text{ } if \text{ } \theta \leq \theta^* \end{cases} \tag{24}$$

and from (23) we have $\underline{\theta} < \theta^* < \theta^{FB}$. Q.E.D.

If the MHRP does not obtain, then there exist one or more solutions to (23). It is shown in the Appendix that the optimal decision rule still has the form (24), where $\theta^* < \theta^{FB}$ is a root of (23) determined by F.

When the regulator cannot directly observe the cost of bypass, it must give the firm an incentive to reveal its cost. The intuition for Proposition 2 (and Proposition 3 to follow) is fostered by considering the possible types of a firm instead as a continuum of firms contemplating bypass.

The likelihood of bypass under private information cannot be less than the efficient likelihood under full information: Firms that can be more efficiently supplied by an alternate producer than the utility remain so, and cannot be economically deterred from leaving the system. The firm on the margin under full information will not be retained under private information, however. Retaining this firm would come at the cost of all inefficient firms imitating this type, avoiding the appropriation of their surplus to consumers. There is a limit to how far the regulator will go, of course: At some point, the cost of losing another firm from the system exceeds the loss to induce incentive compatibility among the remaining firms, giving us a marginal type under private information with a lower opportunity cost than that under the first best. Hence, there is too much bypass when agents have private information.

The regulator uses the transfer function to appropriate for consumers the surplus from the firms with a high willingness-to-pay for utility service. Implementability of the decision rule given in Proposition 1 corresponds to a unique transfer function given $\{p,z\}$, the properties of which yield Proposition 3.

PROPOSITION 3: *(i) Efficient firms receive no information rent,*

(ii) Any firm that remains on the system pays a strictly positive transfer,

(iii) Any inframarginal firm on the system makes a strictly positive profit.

Proof: By (12) and (14), implementability requires the transfer satisfy

$$t(\theta) = \Pi(\bar{\theta}) - \int_{\theta}^{\bar{\theta}} z(\omega)\, d\omega - z(\theta)\,\theta - (1-z(\theta))\,U(p(\theta)) \qquad (25)$$

Consider $\theta > \theta^*$: By Proposition 2, $z(\theta) = 1$ so $z(\theta)$ non-decreasing and $\Pi(\bar{\theta}) = \bar{\theta}$ imply $t(\theta) = 0$, which gives (*i*). Consider $\theta \leq \theta^*$: Then $z(\theta) = 0$ so $t(\theta) = \theta^* - U(m)$. By Proposition 2, $\theta^* < \theta^{FB} \equiv U(m)$, which gives (*ii*). Moreover, for $\theta < \theta^*$, the transfer is constant so by (12), $\Pi(\theta) = \theta^*$. But a type $\theta < \theta^*$ has a willingness to pay given by the lower envelope of the halfspace of individually rational payoffs $\Pi(\theta) \geq \theta$, so by (23) it earns rent $\theta^* - \theta = U(m) - (1-\alpha)F(\theta^*)/F'(\theta^*) - \theta > 0$. Hence, (*iii*).

Q.E.D.

Despite appearing to contradict the conclusions obtained in "standard" asymmetric information models, Proposition 3 is intuitive. High θ, or efficient types, will correctly choose to bypass without any additional incentives from the regulator. Low θ types will wish to mimic a more efficient type, but only up to a point. Mimicking a type beyond the highest type which the regulator wishes to retain, θ^*, will incur a bypass-inducing policy which all inefficient types would find suboptimal ex post.

The incentive compatibility constraint is only an issue among the inefficient types. Each prefers to imitate the most efficient type *which will be retained* in equilibrium. Since all firms remaining on the system pay the same price, to satisfy incentive compatibility they must pay the same transfer, namely, that of the marginal type. The marginal type is, by definition, indifferent between the policy inducements $\{p,t\}$ and the payoff to bypassing the utility, θ^*. Because the regulator wishes to appropriate some surplus from the high reservation price inframarginal types, the indifferent type is decreasing in the transfer required of remaining firms. How far this type moves away from the first-best depends upon the regulator's beliefs and preferences over income distribution. Hence, the inefficient firms all pay an "information tax", determined by the regulator's prior over how efficient the threshold type is.

In summary, the optimal policy can be interpreted as follows. In response to a request for a bypass policy from a firm contemplating bypass, the regulator determines its prior and thus the threshold θ^* beyond which it is not economic to retain a firm from bypassing. A firm that reports a type greater than the threshold is required to bypass, that is, it is "refused a price" at which to continue service. A firm that reports a type below the threshold is assured an efficient price at the utility's marginal cost, but will pay a transfer to the firm to offset the fixed cost of utility service otherwise borne by the consumers. This tax is strictly increasing as the regulator's preference over the distribution of social surplus becomes more heavily weighted toward the consumers.

5. A Graphical Characterization

With the proof of Propositions 1 through 3, we have completely characterized the regulator's optimal policy, M^*. Nevertheless, it is useful to consider a graphical depiction of the optimal bypass policy. Figure 1 depicts the payoff to the downstream firm as a function of its opportunity cost, θ. The individual rationality constraint of the firm is given by the halfspace lying (weakly) above the 45° line. Under full information, the regulator sets its policy so that the firm is exactly indifferent between bypassing and remaining on the system, regardless of type. Hence, the payoff function under full information is the line $\Pi(\theta)=\theta$.[21]

The first-best has the marginal firm located under the intersection of the lines $\Pi(\theta)=U(m)$ and $\Pi(\theta)=\theta$. The value $U(m)$ is the maximum payoff achievable by a (non-bypassing) firm which faces a price equal to the utility's marginal cost. Each type to the right of the firm which achieves this payoff, type θ^{FB}, will strictly prefer to bypass. Note that the firm's problem as originally specified in (3) also implies that $\theta^{FB}=U(m)$.

Under private information, the marginal type shifts to θ^*, so that the bypass region with asymmetric information $(\theta^*,\bar{\theta}]$ exceeds the bypass region under full information. The marginal type under the first-best would remain under a price of m only, but would rather exit than pay the transfer required of all types remaining on the system. The tax on all types remaining on the system induces types in a neighborhood to the left of θ^{FB} to prefer to bypass instead, strictly expanding the bypass region.

Because all inframarginal types $\theta<\theta^*$ prefer to mimic the marginal type θ^*, incentive compatibility constrains the transfer policy to treat all inframarginal types equally. The tax on all types remain-

[21]Since at stage 0 the firm is assumed to be a utility customer, we assume that a firm left indifferent under a bypass policy will continue to maintain utility service.

ing on the system is therefore the "information tax" $(1-\alpha)F(\theta^*)/F'(\theta^*)$ determined by the regulator's prior at the marginal type. The lower shaded area in Figure 1 represents the rent earned by the inefficient types after paying an information tax which does not fully appropriate their willingness to pay. Note that, even under the optimal policy, the existence of asymmetric information between the firm and the regulator induces a deadweight social loss relative to the first-best.

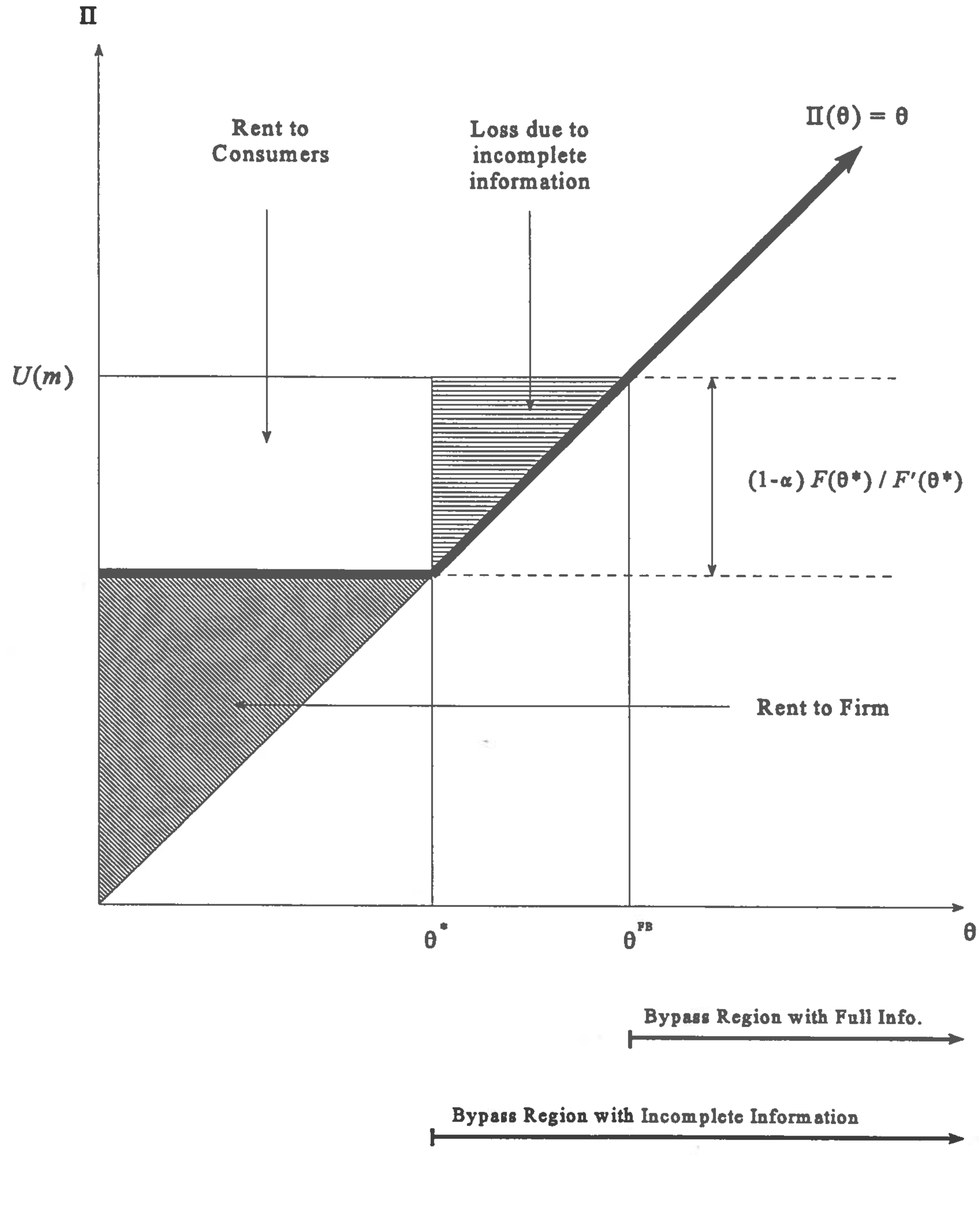
6. Conclusion

In both the electric power and telecommunications industries, regulated firms are commonly required to sell at prices set by average-cost rules. With the advent of new small-scale technologies, this price distortion gives utility customers an incentive to bypass the utility's system. Exit forces the fixed cost of capacity built to serve the departing firm to be reallocated to the utility's remaining consumers. This stranded capacity issue, along with concern over distributive goals underlying the regulation of natural monopolies, has made bypass a source of much contention in the regulatory arena.

From the analysis of the bypass problem under incomplete information, it is clear that current regulatory policies which offer any price above marginal cost to a firm threatening exit are not optimal. Such policies give rise to opportunistic behavior by firms which would never prefer to abandon utility service, and may result in net welfare loss when regulation is administered with regard to the distribution of social surplus among customers. Given this private information, we have shown that there exist optimal policies which eliminate the opportunistic behavior, but the cost of achieving this is more bypass than is efficient under complete information.

The strategies developed in this paper may go some way toward identifying a more appropriate regulatory treatment of bypass. Nevertheless, extensions of our analysis remain to be pursued. Foremost is how a regulator should account for the utility's behavior when the utility is not indifferent to bypass outcomes. We have assumed a traditional rate-of-return framework in our analysis, but the presence of regulatory lag, prudence reviews, or incentive regulation mechanisms will give a utility some incentive to retain a potential bypasser. This coincident incentive should assist the regulator in developing a policy to deter inefficient bypass, although distributional concerns will continue to drive a wedge between the regulator and the regulated. We leave these issues open as avenues for future research.

Figure 1: An Optimal Bypass Policy



Appendix

Proof of Lemma 1

The proof of Lemma 1 is a well-known argument. The global incentive compatibility constraint in (6) is equivalent to

$$\pi(\theta;\theta) \geq \pi(\hat{\theta};\theta) \qquad \text{(IC 1)}$$

$$\pi(\hat{\theta};\hat{\theta}) \geq \pi(\theta;\hat{\theta}) \qquad \text{(IC 2)}$$

$\forall \hat{\theta} \neq \theta$. Consider $\hat{\theta} > \theta$. Using the definition of $\pi(\hat{\theta};\theta)$ in (5),

$$\pi(\hat{\theta};\theta) - \pi(\hat{\theta};\hat{\theta}) = -z(\hat{\theta})[\hat{\theta} - \theta]$$

so by (IC 1)

$$\pi(\theta;\theta) - \pi(\hat{\theta};\hat{\theta}) \geq -z(\hat{\theta})[\hat{\theta} - \theta].$$

Similarly,

$$\pi(\theta;\hat{\theta}) - \pi(\theta;\theta) = z(\theta)[\hat{\theta} - \theta]$$

so by (IC 2)

$$\pi(\hat{\theta};\hat{\theta}) - \pi(\theta;\theta) \geq z(\theta)[\hat{\theta} - \theta].$$

Therefore

$$z(\theta) \leq \frac{\Pi(\hat{\theta}) - \Pi(\theta)}{\hat{\theta} - \theta} \leq z(\hat{\theta}).$$

So $z(\theta)$ is non-decreasing in θ. Since $z(\theta) \geq 0$, Π is non-decreasing and therefore differentiable almost everywhere. Taking limits as $\hat{\theta} \to \theta$ gives:

$$\frac{d\Pi(\theta)}{d\theta} = z(\theta) \quad a.e.$$

An analogous argument obtains for $\hat{\theta} < \theta$. Q.E.D.

Proof of Lemma 2

Consider the local incentive compatibility condition (11). Integrating gives (14), which for $\hat{\theta}$ is

$$\Pi(\hat{\theta}) = \Pi(\bar{\theta}) - \int_{\hat{\theta}}^{\bar{\theta}} z(\theta)\, d\theta.$$

Now, from the revealed preference argument in the proof of Lemma 1,

$$\pi(\hat{\theta};\theta) = \pi(\hat{\theta};\hat{\theta}) - z(\hat{\theta})\,[\hat{\theta} - \theta].$$

So

$$\pi(\hat{\theta};\theta) = \Pi(\bar{\theta}) - \int_{\hat{\theta}}^{\bar{\theta}} z(\theta)d\theta - z(\hat{\theta})\,[\hat{\theta} - \theta]$$

but

$$\Pi(\bar{\theta}) = \Pi(\theta) + \int_{\theta}^{\bar{\theta}} z(\omega)d\omega\,.$$

So

$$\pi(\hat{\theta};\theta) = \Pi(\theta) + \int_{\theta}^{\hat{\theta}} z(\omega)d\omega - z(\hat{\theta})\,[\hat{\theta} - \theta]$$

or

$$\pi(\hat{\theta};\theta) = \Pi(\theta) + \int_{\theta}^{\hat{\theta}} [z(\omega) - z(\hat{\theta})]\,d\omega$$

So global incentive compatibility ($\Pi(\theta) \geq \pi(\hat{\theta};\theta)$) obtains if the integral term is never positive. It suffices that $z(\theta)$ is non-decreasing $\forall\ \theta$: If $\hat{\theta} > \theta$, the integrand is negative, and if $\hat{\theta} < \theta$, the direction of integration is reversed. Q.E.D.

Proof of Proposition 2

PROPOSITION 2: When agents have private information about the cost of bypass, the likelihood of bypass is too high relative to the first-best; that is,

$$\inf\{\theta\in\Theta:\ z^*(\theta)=1\} < \sup\{\theta\in\Theta:\ z^{FB}(\theta)=0\}$$

where z^* and z^{FB} are non-decreasing and are optimal decision rules under asymmetric information and full information, respectively.

Proof: Recall our assumptions:

$U(m)$ satisfies $\underline{\theta}<U(m)<\overline{\theta}$; (A1)

$0<\alpha<1$; (A2)

and under asymmetric information,

F is absolutely continuous with density $f>0$ on $\Theta=[\underline{\theta},\overline{\theta}]$. (A3)

For notational convenience, define $R(\theta) = (1-\alpha)F(\theta)/f(\theta)$, $\theta\in\Theta$.

Under asymmetric information, the regulator's problem is to choose a decision rule $z^*:\Theta\rightarrow[0,1]$ to

$$\max \int_{\Theta} h(p^*(\theta),z(\theta);\theta)\ dF \qquad \textit{subject to:} \quad z'\geq 0,\quad 0\leq z\leq 1 \tag{A4}$$

where $p^*(\theta) = m$ from Proposition 1, $z'\geq 0$ suffices for incentive compatibility by Lemma 2, and

$$h(p^*(\theta),z(\theta);\theta) = \{v + (1-z(\theta))U(m) + z(\theta)\theta + R(\theta))\} \tag{A5}$$

is a continuous surface on $\Theta\times[0,1]$.

Treat (A4) as an optimal control problem with state variable $z(\theta)$ and costate (control) $u(\theta)\equiv z'(\theta)$. Define the Hamiltonian:

$$\mathcal{H} = h(z;\theta)f(\theta) + \mu(\theta)u(\theta) + \nu(\theta)u(\theta) + \lambda_1(\theta)z(\theta) + \lambda_2(\theta)(1-z(\theta)) \tag{A6}$$

where $\mu(\theta)$ is the Pontryagin multiplier for the state equation $u(\theta)=z'(\theta)$, and ν, λ_1, and λ_2 are the Lagrangian multipliers for the inequality constraints $u\geq 0$, $z\geq 0$, and $z\leq 1$, respectively. By the Maximum Principle, necessary conditions for z^* to be maximal are

$$\partial\mathcal{H}/\partial u = 0 = \mu + \nu \tag{A7}$$

$$-\partial\mathcal{H}/\partial z = \mu' = -\{h_z(\theta)f(\theta) + \lambda_1(\theta) - \lambda_2(\theta)\} \tag{A8}$$

in addition to non-negativity of the Lagrangian multipliers, the four program constraints, and the corresponding complementary slackness conditions.

Observe first that since the terminal values of z^* are free, we have the transversality conditions $\mu(\underline{\theta}) = \mu(\overline{\theta}) = 0$. Next, observe that (A3) implies $R(\underline{\theta}) = 0$ and $R(\theta) > 0$ for $\theta > \underline{\theta}$. Since $h_z(\theta) = \theta - U(m) + R(\theta)$ and $\underline{\theta} < U(m) < \overline{\theta}$, we have $h_z(\underline{\theta}) < 0$, $h_z(\overline{\theta}) > 0$, h_z continuous, and $\{\theta \in \Theta : h_z(\theta) = 0\}$ non-empty.

Let $\varepsilon = \overline{\theta} - \sup\{\theta \in \Theta : h_z(\theta) = 0\}$. Then $\varepsilon > 0$ and $h_z > 0$ on $N_\varepsilon = (\sup\{\theta \in \Theta: h_z(\theta) = 0\}, \overline{\theta}]$ by continuity of h_z. Choose $\theta < \overline{\theta}$, $\theta \in N_\varepsilon$. Then $\int_{(\theta,\overline{\theta})} h_z \cdot f > 0$. Now since $\nu \geq 0$, $\mu \leq 0$ by (A7). Integrating (A8) using the upper transversality condition yields

$$0 \geq \mu(\theta) = \int_{(\theta,\overline{\theta})} h_z \cdot f + \lambda_1 - \lambda_2 \tag{A9}$$

so $\int_{(\theta,\overline{\theta})} \lambda_2 - \lambda_1 > 0$. Now from (A6), $\lambda_1 > 0 \Rightarrow \lambda_1 = -h_z \cdot f$, so the non-negativity constraint $\lambda_1 \geq 0$ implies that $\lambda_1 = 0$ on N_ε. Thus $\int_{(\theta,\overline{\theta})} \lambda_2 > 0$ for all $\theta \in N_\varepsilon \cap \{\theta < \overline{\theta}\}$, and so $\lambda_2 > 0$ a.e. on N_ε. Now since $\lambda_2(1-z) \equiv 0$, $z \leq 1$ and z non-decreasing imply $z^* = 1$ everywhere on N_ε, and therefore

$$\inf\{\theta \in \Theta: z^*(\theta) = 1\} \leq \sup\{\theta \in \Theta: h_z(\theta) = 0\}. \tag{A10}$$

Now under full information, $R(\theta) \equiv 0$ and the unique solution to $h_z(\theta) = 0$ is $\theta = U(m)$. Let $N_\delta = [\underline{\theta}, U(m))$ and choose $\theta \in N_\delta \cap \{\theta > \underline{\theta}\}$. Then $\int_{(\underline{\theta},\theta)} h_z \cdot f < 0$, and integrating (A8) using the lower transversality condition yields

$$0 \leq -\mu(\theta) = \int_{(\underline{\theta},\theta)} h_z \cdot f + \lambda_1 - \lambda_2 \tag{A11}$$

so $\int_{(\underline{\theta},\theta)} \lambda_1 - \lambda_2 > 0$. Now from (A6), $\lambda_2 > 0 \Rightarrow \lambda_2 = h_z \cdot f$, so λ_2 non-negative implies that $\lambda_2 = 0$ on N_δ.

Thus $\int_{(\underline{\theta},\theta)}\lambda_1 > 0$ for all $\theta \in N_\delta \cap \{\theta > \underline{\theta}\}$, and so under full information $\lambda_1 > 0$ a.e. on N_δ. Since $\lambda_1 \cdot z \equiv 0$, $z \geq 0$ and z non-decreasing imply $z^{FB} = 0$ everywhere on N_δ. Thus

$$U(m) \leq \sup\{\theta \in \Theta:\ z^{FB}(\theta) = 0\}. \tag{A12}$$

(Note that by the same argument, under asymmetric information $z^* = 0$ on $[\underline{\theta}, \inf\{\theta \in \Theta: h_z(\theta) = 0\})$.)

Proposition 2 is now immediate from the observation that under asymmetric information, $R(\theta) > 0$ for $\theta > \underline{\theta}$ and therefore

$$\sup\{\theta \in \Theta:\ h_z(\theta) = 0\} < U(m). \tag{A13}$$

Q.E.D.

For the sake of completeness, we now characterize z^* and show that the form (24) is an optimal policy regardless of the MHRP. First, we need a lemma.

LEMMA: $z' = 0$ except possibly where $\mu = 0$ and $h_z \cdot f = 0$.

Proof:

By preceding arguments, we have that $z^*(\theta) = 0$ for θ near $\underline{\theta}$, and that $z^*(\theta) = 1$ for θ near $\bar{\theta}$. Let z denote a feasible candidate solution satisfying these terminal conditions. By the complementary slackness condition $\mu \cdot z' \equiv 0$, $z' = 0$ except possibly where $\mu = 0$.

Let $S = \{\theta \in \Theta : z'(\theta) \neq 0\}$; since z satisfies the terminal conditions, S is non-empty and $S \subset (\underline{\theta}, \bar{\theta})$ (define $z'(\theta)$ to be the derivative of z from above or below if θ is a lower or upper boundary point of Θ, respectively). It suffices to show that $h_z(s) \cdot f(s) = 0$, $s \in S$.

Choose $s \in S$, and let θ_m and θ_n be sequences in Θ such that $\theta_m \uparrow s$ and $\theta_n \downarrow s$. Since $z'(s) \neq 0$, by complementary slackness $\mu(s) = 0$. Thus $\mu \leq 0$ and continuity of the Pontryagin multiplier imply $0 \geq \mu(\theta_m) \to 0$ and $0 \geq \mu(\theta_n) \to 0$ as $\theta_m \uparrow s$ and $\theta_n \downarrow s$, respectively.

Observe that z non-decreasing and $\lambda_2(1-z) \equiv 0$ imply

$$s \leq \inf\{\theta \in \Theta : z(\theta) = 1\} \leq \sup\{\theta \in \Theta : \lambda_2(\theta) = 0\} \tag{A14}$$

so that $\lambda_2(\theta_m) = 0 \; \forall \; \theta_m < s$, and so as $\theta_m \uparrow s$,

$$0 \leq -\mu(\theta_m) = \int_{(\underline{\theta},\theta_m)} h_z \cdot f + \lambda_1 \rightarrow 0 . \tag{A15}$$

Now $\lambda_1 \geq 0$ and $\lambda_1 \leq \sup|h_z \cdot f| < \infty$ imply that $\int_{(\underline{\theta},\theta_m)} \lambda_1$ is a bounded non-decreasing sequence, and therefore convergent. So by (A15), $-\int_{(\underline{\theta},\theta_m)} h_z \cdot f$ is bounded above by its limit. Thus, $\nexists \; M$ such that $h_z(\theta_m) \cdot f(\theta_m) > 0 \; \forall \; m > M$, $\Rightarrow$ liminf $h_z(\theta_m) \cdot f(\theta_m) \leq 0$. Since $h_z \cdot f$ is continuous on S, we have that $h_z(s) \cdot f(s) \leq 0$.

Similarly, z non-decreasing and $\lambda_1 \cdot z \equiv 0$ imply

$$\inf\{\theta \in \Theta : \lambda_1(\theta) = 0\} \leq \sup\{\theta \in \Theta : z(\theta) = 0\} \leq s \tag{A16}$$

so that $\lambda_1(\theta_n) = 0 \; \forall \; \theta_n > s$, and so as $\theta_n \downarrow s$,

$$0 \geq \mu(\theta_n) = \int_{(\theta_n,\bar{\theta})} h_z \cdot f - \lambda_2 \rightarrow 0 . \tag{A17}$$

Likewise, $\lambda_2 \geq 0$ and bounded imply that $\int_{(\theta_n,\bar{\theta})} h_z \cdot f$ is bounded above by its limit. Thus, $\nexists \; N$ such that $h_z(\theta_n) \cdot f(\theta_n) < 0 \; \forall \; n > N$, $\Rightarrow$ limsup $h_z(\theta_n) \cdot f(\theta_n) \geq 0$. By continuity, $h_z(s) \cdot f(s) \geq 0$ and therefore $h_z(s) \cdot f(s) = 0$, which completes the lemma. Q.E.D.

Construction of z^*

Given the lemma, construction of z^* is straightforward. Let Θ_0 denote the set of all solutions to the equation

$$h_z(\theta) \cdot f(\theta) \equiv [\theta - U(m) + R(\theta)] f(\theta) = 0. \tag{A18}$$

By previous arguments, (A1) and (A3) imply Θ_0 non-empty and $\Theta_0 \subset \Theta$. Let $\theta_{\min} = \inf(\Theta_0)$ and $\theta_{\max} = \sup(\Theta_0)$. From the proof of Proposition 2, we have $z^*(\theta) = 0$ for $\theta < \theta_{\min}$ and $z^*(\theta) = 1$ for $\theta > \theta_{\max}$.

Suppose first that Θ_0 is a finite set. Clearly if $\theta_{min} = \theta_{max}$, our solution is:

$$z^*(\theta) = \begin{cases} 1 \text{ if } \theta > \theta^* \\ 0 \text{ if } \theta \leq \theta^* \end{cases} \tag{A19}$$

where $\theta^* = \theta_{min} = \theta_{max}$ (the equality assignment in (A19) being arbitrary).

If not, then $\theta_{min} < \theta_{max}$. Let $\theta_1 = \inf\{\theta \in \Theta_0 : \theta > \theta_{min} \wedge \mu(\theta) = 0\}$, so that $\theta_{min} < \theta_1 \leq \theta_{max}$. If $\theta_1 = \theta_{max}$, then by the lemma, z^* is constant on $(\theta_{min}, \theta_{max})$. Now z^* optimal implies

$$z^* \in \underset{0 \leq z \leq 1}{\operatorname{argmax}} \int_{\theta_{min}}^{\theta_{max}} h(p^*, z; \theta)\, dF \tag{A20}$$

and since h is uniformly bounded on Θ,

$$\frac{d}{dz} \int_{\theta_{min}}^{\theta_{max}} h(p^*, z; \theta)\, dF = \int_{\theta_{min}}^{\theta_{max}} h_z(p^*, z; \theta)\, dF \tag{A21}$$

But $h_z(p^*(\theta), z(\theta); \theta) = h_z(\theta)$ so the right-hand side of (A21) is a constant function of z, and therefore for $\theta \in (\theta_{min}, \theta_{max})$, $z^*(\theta) = 0$ or $z^*(\theta) = 1$ as the right-hand side of (A21) is negative or positive, respectively.

Hence our solution is of form (A19), except that

$$\theta^* = \begin{cases} \theta_{min} & \text{if } \int_{\theta_{min}}^{\theta_{max}} h_z\, dF > 0 \\ \theta_{max} & \text{if } \int_{\theta_{min}}^{\theta_{max}} h_z\, dF \leq 0 \end{cases} \tag{A22}$$

where again the equality assignment is arbitrary.

More generally, if $\theta_{min} < \theta_{max}$, then let $\theta_0 = \theta_{min}$ and recursively define $\theta_n = \inf\{\theta \in \Theta_0 : \theta > \theta_{n-1} \wedge \mu(\theta) = 0\}$ for $n = 1, 2, \ldots, (\#\Theta_0 - 1)$. By the lemma, z is constant on each subinterval (θ_{min}, θ_1), (θ_1, θ_2), ..., $(\theta_{n-1}, \theta_{max})$, and by application of the argument following (A20), either $z^*(\theta) = 0$ or $z^*(\theta) = 1$ on each subinterval. By the monotonicity constraint $z' \geq 0$, the optimal solution has the form (A19) where θ^* is a single switch point at some θ_n given by comparing the integrals $A_n = \int_{\theta_{n-1}}^{\theta_n} h_z\, dF$ for $n = 1, 2, \ldots, (\#\Theta_0 - 1)$. A_n may be interpreted as the F-weighted "average slope" of h (with respect to z) on (θ_{n-1}, θ_n).

Finally, if Θ_0 is not finite, then there exist intervals in Θ on which $h_z = 0$. Let M be the number of disconnected intervals, $\Delta\theta_m \subset \Theta$, $m = 1, 2, \ldots, M$, on which $h_z = 0$; M exists since h_z is uniformly continuous. Now since $h_z \cdot f$ is flat on each subinterval $\Delta\theta_m$, given z^* on $\bigcap_m (\Delta\theta_m)^c$ any monotone z on Θ is optimal. Thus, we may determine an optimum z^* of form (A19) using the previous construction for θ^* with the modification that if $\theta_n = \inf(\Delta\theta_m)$ for some n, m, then set $\theta_{n+1} = \sup(\Delta\theta_m)$, where n now runs from 0 to $\#(\bigcap_m \{\Theta_0 \cap (\Delta\theta_m)^c\}) + 2M < \infty$.

References

Baron, David P. (1989). Design of Regulatory Mechanisms and Institutions. In R. Schmalensee and R.D. Willig, eds., *Handbook of Industrial Organization,* Volume II. Amsterdam: North-Holland, Chapter 24.

Baron, David P. and Roger B. Myerson (1982). Regulating a Monopolist with Unknown Costs. *Econometrica* 50:4 (July), 911-30.

Braeutigam, R.R. (1979). Optimal Pricing with Intermodal Competition. *American Economic Review* 69, 38-49.

Broadman, Harry G., and Joseph P. Kalt (1989). How Natural is Monopoly? The Case of Bypass in Natural Gas Distribution Markets. *Yale Journal on Regulation* 6:181, 181-207.

Caillaud, Bernard (1990). Regulation, Competition, and Asymmetric Information. *Journal of Economic Theory* 52, 87-110.

California Public Utilities Commission (1994). Order Instituting Rulemaking and Investigation on the Commission's Proposed Policies Governing Restructuring California's Electric Services Industry and Reforming Regulation. Docket # R.94-04-031 and I.94-04-032, April 20.

Demski, Joel, David Sappington, and Pablo Spiller (1987). Managing Supplier Switching. *RAND Journal of Economics* 18, 77-97.

Einhorn, Michael A. (1987). Optimality and Sustainability: Regulation and Intermodal Competition in Telecommunications. *RANDJournal of Economics* 18:4, 550-63.

Fudenberg, Drew, and Jean Tirole (1991). *Game Theory.* Cambridge: MIT Press.

Guesnerie, Roger, and Jean-Jacques Laffont (1984). A Complete Solution to a Class of Principal-Agent Problems with an Application to the Control of a Self-Managed Firm. *Journal of Public Economics* 25, 329-69.

Kamien, Morton I. and Nancy L. Schwartz (1991). *Dynamic Optimization*, 2nd Ed. New York: Elsevier Science Publishing Co., Inc.

Katz, Michael (1991). Game Playing Agents: Unobservable Contracts as Precommitments. *RAND Journal of Economics,* 22, 307-328.

Laffont, Jean-Jacques, and Jean Tirole (1986). Using Cost Observations to Regulate Firms. *Journal of Political Economy* 94, 614-41.

Laffont, Jean-Jacques, and Jean Tirole (1990). Optimal Bypass and Cream Skimming. *American Economic Review* 80:5, 1042-61.

Laffont, Jean-Jacques, and Jean Tirole (1993). A Theory of Incentives in Procurement and Regulation. Cambridge: MIT Press.

MacAvoy, Paul W., Daniel F. Spulber, and Bruce E. Stangle (1989). Is Competitive Entry Free? Bypass and Partial Deregulation in Natural Gas Markets. *Yale Journal on Regulation* 6:181, 209-247.

Marnay, Chris (1989). Special Electricity Contract in California. Universitywide Energy Research Group Working Paper #UER-242 (October), University of California.

Maskin, E., and J. Riley (1984). Monopoly with Incomplete Information. *RAND Journal of Economics* 15, 171-96.

Myerson, R. (1979). Optimal Auction Design. *Mathematics of Operations Research* 6, 58-73.

Riordan, Michael and David Sappington (1987). Awarding Monopoly Franchises. *American Economic Review* 77, 375-87.

Rose, Kenneth, and John F. McDonald (1981). Economics of Electricity Self-Generation by Industrial Firms. *The Energy Journal* 12:2, pp. 47-66.