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REGULATING COMPLEMENTARY PRODUCTS: A Problem of Institutional Choice

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Abstract

Optimal regulation, subject to informational constraints, is analyzed for industries where production requires complementary inputs. A regulatory policy issue is whether supply in these industries should be "bundled" or "unbundled". Bundled supply calls for regulation of a vertically integrated industry. Unbundled supply allows regulation to be confined to natural monopoly services with access to essential facilities at regulated prices. A main result is that unbundling supply introduces an information cost that is similar to the problem of "double marginalization" in the pricing of complementary products. Unbundling may be advantageous if it allows competition in non-monopoly services, however the informational cost can exceed the benefits of competition.

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I. Introduction

The introduction of competition into traditionally regulated industries gives regulators a choice in many situations of the institutional structure for the delivery of services. In the supply of natural gas, the Federal Energy Regulatory Commission (FERC) and local regulators have discretion over whether distribution companies may contract for gas independently of pipeline services, or whether they must contract for a bundled product.[1] In telecommunications, the Federal Communications Commission has dealt with the issue of separation of local and long distance telephone services. In electric power, independent power producers (IPPs) provide regulators with an alternative to the local utility for power supply planning.[2] The local utility offers a bundled product that combines bulk power and transmission services and the IPP is a potential source of unbundled bulk power.

In each of these examples, delivery of the regulated service to final consumers requires a component that is supplied by the regulated firm, even if other components of the product are supplied competitively. Natural gas supplies must be combined

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[1] The FERC launched a major inquiry into the structure of regulated natural gas services with its 1991 Notice of Proposed Rulemaking (see FERC, 1991). The proposed rules would require interstate pipelines offering transportation services to sell their gas on an unbundled basis.

[2] The Federal Energy Regulatory Commission defines an IPP as "producers other than QFs [qualified facilities with a mandated right to sell power under the Public Utility Regulatory Policies Act of 1978] that are unaffiliated with franchised utilities in the IPPs' market areas and that for other reasons lack significant market power." (FERC 1987, p.1).

with (regulated) pipeline carriage, long distance carriers require access to (regulated) local switching, and independent bulk power producers require access to (regulated) transmission. This paper examines the circumstances under which unbundled supply of component products ("component supply") or integrated supply of a bundled product ("vertical integration") is advantageous to a regulator.

Electricity provides an appealing context to study this institutional choice. The transmission grid is generally viewed to be a natural monopoly, while the supply of bulk energy is potentially competitive (see, e.g. Joskow and Schmalensee, 1983). Accordingly, recent initiatives to deregulate electricity supply focus on introducing alternatives to the local utility for the provision of bulk energy.[3] Assuming that transmission is regulated in any case, bulk power can be contracted as a bundled product with transmission services provided by the regulated utility, or as a separate product that must be combined with regulated transmission services.

Figure 1 illustrates the problem of institutional choice. A regulated utility ("U") owns a transmission line from point A to final consumers at point B. The regulator has a demand for one unit of incremental power supply. An IPP ("I") is available to supply one unit of power at point A. Alternatively, the local utility ("U") can supply one unit by itself at point A. Both the utility and the IPP require use of the transmission line to transport the power from point A to consumers at point B.

Bulk energy and transmission are complementary inputs for the supply of electricity. The IPP has private information about the cost of bulk energy. The local utility has private information about the cost of transmission service and the cost of the

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[3] Some proposals for the deregulation of the electric power grid focus on establishing property rights for transmission services (see, e.g. Hogan, 1991). However, markets for transmission rights are likely to be highly concentrated, and thus vulnerable to strategic behavior.

bundled product, comprised of transmission and generation by the regulated firm. The regulator has incomplete information about these costs. The cost of bulk energy depends on managerial ability in project design, construction, and operation, and on environmental conditions that are likely to be the private information of the supplier. Asymmetric information about transmission stems from its opportunity cost, which is the private information of the local utility. Transmission capacity that is not used to import power produced by the utility or the IPP at point A is nonetheless valuable as a means to import (or export) economy energy which is in temporary surplus at other utilities and can be used to displace higher cost local sources of supply. Transmission capacity also has value as a means to import emergency energy to replace losses from local outages. Information about the opportunity cost of transmission is likely to be largely confined to the local utility.[4]

Section II characterizes optimal regulatory strategies in an industry organization where each component is supplied by a separate firm. An IPP produces bulk power and the local utility provides transmission access, each producer with private information about its costs. Although this is, in general, a two-dimensional revelation problem, conditions are derived for which total cost is a sufficient statistic for optimal production, i.e. the optimal production policy can be expressed as a function of the sum of the costs for each component. Section III shows that the regulator can implement the optimal (two-dimensional) regulatory scheme for separate component supply by contracting only with one of the firms (arbitrarily chosen), and allowing that firm to subcontract with the other component supplier.

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[4] Spiewak and Weiss (1991) discuss the opportunity cost of transmission and FERC regulation of transmission services. The opportunity cost of transmission can be much larger than its replacement cost. Some proposals for mandatory transmission access specify replacement cost as the upper bound of the transmission tariff, yet opportunity cost is clearly the correct measure of value.

An optimal subcontracting scheme specifies a payment to one of the firms conditional on production and a take-it-or-leave-it price to the other firm, both conditional on the cost report of the first firm. This strategy yields the same expected payoff to the regulator as the optimal strategy when the regulator deals (separately) with both firms. Moreover, with the appropriate choice of a franchise fee, the regulator can delegate completely regulation of the second firm to the first firm. The regulator need only specify a price for the first firm and a franchise fee, both conditional of the first firm's reported cost. The firm would have an incentive to subcontract with the second firm at a price that is optimal for the regulator given her information constraints.

Section IV compares the regulator's expected return from contracting separately with the two component suppliers to the expected return from contracting with a vertically integrated producer with private information about the two components. In the electric power example, the vertically integrated supplier is the local utility, assumed to have the same technology for bulk power production as the IPP. The regulator's optimal strategy with vertical integration is shown to depend only on the firm's reported total cost. In contrast, with component supply the regulator may choose a more general policy that depends on the reports of both component costs. Section IV shows that, in those instances where total cost is a sufficient statistic for optimal production under component supply, the regulator's expected payoff is strictly higher with vertical integration. Under these conditions, the regulator does not benefit from unbundling the product and contracting separately for bulk power and transmission access. Appendix A shows by example that the regulator would prefer vertical integration also in many situations where the sufficient statistic property does not apply.

The reason why vertically integrated supply is better for the regulator is related to the problem of "double marginalization" in successive monopoly, as described by Cournot (1927). With component supply, the IPP ignores the negative consequences of a high reported cost for bulk power on the profits of the local utility and the local utility ignores the consequence of a high reported cost for transmission access on the profits of the IPP. This tends to make firms more willing to overstate costs under component supply, thus increasing firms' information rents.

Unbundling supply can benefit the regulator if it leads to a more favorable probability distribution for the cost of bulk energy, either because the IPP has a lower expected cost than the local utility or because competition among IPPs expands the production possibilities for the bulk energy component of power supply. Section V relates the structure of information to the structure of the market for bulk energy supply. If the vertically integrated firm would operate only a single plant, the possibility of even modest levels of competition among IPPs is sufficient for the regulator to prefer component supply. The comparison is more problematic if the vertically integrated firm would employ the same technology that would be used under component supply. The regulator benefits in the case of component supply from horizontal competition among independent firms, which reduces information rents for bulk power supply, but vertical integration offers informational advantages associated with eliminating double marginalization. With the same technology in the vertically integrated and component regimes, the regulator may prefer vertical integration in a wide range of circumstances.

Sections VI concludes with a discussion of policy implications and open questions for research. Before proceeding, we note that Baron and Besanko (1992) have independently addressed issues closely related to ours. Their framework provides for a downward sloping demand curve, however our narrower specification of demand yields some sharper results. Also, they consider different subcontracting arrangements. Our subcontracting schemes require that the prime contractor deal with the regulator before making subcontracting arrangements (as in Melamud, Mookherjee, and Reichelstein, 1991), while they consider the contrary case.

II. Regulation of component supply

This section models a regulator contracting for a product made up of two complementary components supplied by two different producers. In the context of the electricity example, one supplier is the local utility, who provides transmission services, and the other is an IPP, who provides bulk electric power. The regulator's optimal procurement policy is determined under the assumption that the component suppliers act independently.

The regulator has a value *V* for one unit of the bundled product, which consists of one unit from each supplier. The supplier of the first component, Producer 1, has cost α and the supplier of the second, Producer 2, has cost β. Producers are privately informed about their own cost. It is commonly believed that costs are independent random variables with densities $f(\alpha)$ and $g(\beta)$, corresponding distribution functions $F(\alpha)$ and $G(\beta)$, and supports [0,A] and [0,B]. The regulator's problem is to design a contract to maximize expected value minus the cost of power. For simplicity, the regulator is assumed to put no welfare weight on either producer's profits. The analysis is easily generalized to allow a positive social value of profit.

According to the revelation principle, any buying mechanism is equivalent to a truthful direct revelation mechanism satisfying individual rationality constraints. Conditional on the reports $(\hat{\alpha}, \hat{\beta})$ by both firms, the regulator's strategy calls for a probability of production $Q(\hat{\alpha},\hat{\beta})$ and payments to each firm $[r(\hat{\alpha},\hat{\beta}), s(\hat{\alpha},\hat{\beta})]$. If Producer 1 with true cost α reports a cost $\hat{\alpha}$, his expected profit is

$$\Pi_1(\hat{\alpha},\alpha) = \int_0^B (r(\hat{\alpha},\beta) - \alpha\, Q(\hat{\alpha},\beta))\, g(\beta)\, d\beta.$$

Define $\Pi_1(\alpha) \equiv \Pi_1(\hat{\alpha},\alpha)$. Incentive compatibility requires

$$\frac{\partial \Pi_1(\alpha)}{\partial \alpha} = -\int_0^B Q(\alpha,\beta)\, g(\beta)\, d\beta \equiv -X(\alpha).$$

Assuming that the individual rationality constraint is binding in expected value for the highest cost producer ($\alpha = A$), then[5]

$$\Pi_1(\alpha) = \int_\alpha^A X(a)\, da. \tag{1}$$

Note that $X(\alpha)$ is the probability that the regulator will accept the good conditional on the report by Producer 1 and assuming truthful reporting by Producer 2. Similarly, for Producer 2

$$\frac{\partial \Pi_2(\beta)}{\partial \beta} = -\int_0^A Q(\alpha,\beta)\, f(\alpha)\, d\alpha \equiv -Y(\beta)$$

and

[5] One might conjecture an alternative characterization that would require only expected profits over both α and β to be non-negative (the individual rationality constraint would be *ex ante*). As each component is characterized by a single probability distribution, expected rents would be zero and production would be efficient under an *ex ante* individual rationality constraint. This is unrealistic, however, as a more complete model would allow for different "types" of firms that differ in the probability distribution of production costs.

$$\Pi_2(\beta) = \int_{\beta}^{B} Y(b)\,db. \tag{2}$$

The regulator's objective is to maximize expected consumer surplus, which under component supply equals

$$W^c = \int_0^A \int_0^B [VQ(\alpha,\beta) - r(\alpha,\beta) - s(\alpha,\beta)]\, f(\alpha)\, g(\beta)\, d\alpha\, d\beta. \tag{3}$$

Integrating (3) by parts using (1) and (2) gives

$$W^c = \int_0^A \int_0^B [V - \alpha - \beta - \frac{F(\alpha)}{f(\alpha)} - \frac{G(\beta)}{g(\beta)}]\, Q(\alpha,\beta)\, f(\alpha)\, g(\beta)\, d\alpha\, d\beta. \tag{4}$$

Assuming $\frac{F(\alpha)}{f(\alpha)}$ and $\frac{G(\beta)}{g(\beta)}$ are non-decreasing, point-wise optimization implies production takes place if and only if

$$V \geq \alpha + \beta + \frac{F(\alpha)}{f(\alpha)} + \frac{G(\beta)}{g(\beta)}. \tag{5}$$

This characterization leads to the following result, the proof of which follows immediately from (5). It is used later in the comparison of regulation under component and vertically integrated supply.

Lemma 1: $\gamma = \alpha + \beta$ *is a sufficient statistic for optimal production under component supply if*

$$\frac{G(\gamma-\alpha)}{g(\gamma-\alpha)} + \frac{F(\alpha)}{f(\alpha)}$$

is independent of α.

The lemma applies if, for example, F(α) and G(β) are symmetric power functions on the unit interval, including the standard uniform case.

Example 1. Assume α and β are each distributed uniformly over [0,1]. Condition (5) implies $Q(\alpha,\beta) = 1$ if $V \geq 2\gamma$, where $\gamma = \alpha+\beta$. Welfare under component supply is

$$W^C = \int_{\alpha=0}^{\min[1,\frac{V}{2}]} \int_{\beta=0}^{\min[1,\frac{V}{2}-\alpha]} [V-2(\alpha+\beta)]\, d\beta\, d\alpha.$$

III. Implementing the optimal contract with component supply

Is there a simple way for the regulator to implement her optimal policy when component products are supplied by independent producers? Consider a mechanism that arbitrarily designates Producer 1 the "prime contractor" and Producer 2 the "subcontractor". The mechanism requires: (i) Producer 1 to offer Producer 2 a take-it-or-leave-it price for production; (ii) production takes place if Producer 2 accepts. Let $[q(\hat{\alpha}), t(\hat{\alpha})]$ denote the price offer to Producer 2 and a transfer to Producer 1 as functions of Producer 1's report, $\hat{\alpha}$. Producer 2 accepts 1's offer if his cost is less than $q(\alpha)$, which occurs with probability $G(q(\alpha))$. Hence Producer 1's expected profit conditional on a report $\hat{\alpha}$ is

$$\Pi_1(\hat{\alpha},\alpha) = t(\hat{\alpha}) - \alpha G(q(\hat{\alpha})).$$

Incentive compatibility and individual rationality imply that Producer 1's expected profit is

$$\Pi_1(\alpha) = \int_{\alpha}^{A} G(q(a))da.$$

Therefore, the regulator's objective function can be written

$$\int_0^A [V-\alpha-q(\alpha)-\frac{F(\alpha)}{f(\alpha)}]G(q(\alpha))f(\alpha)d\alpha. \tag{6}$$

Point-wise optimization of (6) with respect to $q(\alpha)$ yields a first-order condition that can be expressed as

$$V-\alpha-q(\alpha)-\frac{F(\alpha)}{f(\alpha)}-\frac{G(q(\alpha))}{g(q(\alpha))} = 0. \tag{7}$$

Producer 2 accepts if $\beta \leq q(\alpha)$. Therefore, production takes place if

$$V-\alpha-\beta-\frac{F(\alpha)}{f(\alpha)}-\frac{G(\beta)}{g(\beta)} \geq 0.$$

It is verified by substitution that the regulator earns a second-best payoff.

The second-best solution implicitly determines the expected transfer to the prime contractor, $t(\alpha)$. Note further that because of risk-neutrality, this transfer can be expressed arbitrarily as

$$t(\alpha) = p(\alpha)G(q(\alpha)) - r(\alpha) \tag{8}$$

where $p(\alpha)$ is a payment for production and $r(\alpha)$ can be interpreted as a "franchise fee" that is independent of the probability that production takes place. The franchise fee can take any value provided that $t(\alpha)$ supports the second-best optimal policy. Setting $r(\alpha) = 0$, both producers earn positive profits, (i.e. $p(\alpha) \geq \alpha$ and the subcontract accepts only if $q(\alpha) \geq \beta$), and *ex post* individual rationality constraints would be satisfied for both producers.

This scheme requires the regulator to specify a price that the prime contractor must offer to the subcontractor as a function of the prime's reported cost. By setting

$$p(\alpha) = V - \frac{F(\alpha)}{f(\alpha)} \tag{9}$$

and choosing $r(\alpha)$ to satisfy (8), subcontracting can be fully delegated to Producer 1. This follows from the fact that Producer 1 will maximize $[p(\alpha) - \alpha - q]G(q)$ with respect to q, yielding the condition

$$p(\alpha) - \alpha - q(\alpha) - \frac{G(q(\alpha))}{g(q(\alpha))} = 0.$$

With $p(\alpha)$ defined by (9), this is equivalent to (7) and yields a second-best payoff for the regulator. A main advantage of this mechanism is that the regulator need not specify the terms of the subcontract, but can instead delegate subcontracting to the prime contractor.[6] However, because the franchise fee is positive, in general, and production may fail to take place, this subcontracting arrangement does not satisfy *ex post* individual rationality for the prime contractor, although it does by construction satisfy interim rationality.[7]

IV. Regulating vertically integrated supply

In the subcontracting arrangement considered above, the regulator deals exclusively with the producer of one of the components and relies on that producer to subcontract with the second producer for the other component. In many regulatory situations, one of the producers has the ability to supply both components. Electric utilities are typically vertically integrated in both bulk power and transmission services. A central issue in the deregulation of electric power and other industries is the benefit to be obtained from independent supply of components that are supplied as a bundled product by the regulated firm. As a first step in this evaluation, we contrast the regulator's expected payoff when the product is supplied by Producer 1 under the assumption that the firm supplies both components and has the same information structure as the two independent firms. Specifically, we assume that Producer 1 has private information on α and β, where α and β are independent random variables distributed according to the density functions $f(\alpha)$ and $g(\beta)$.

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[6] It does require the prime contractor to "sign a contract" with the buyer before making any subcontracting arrangements.

[7] *Ex post* rationality fails because the prime contractor's payoff may be negative for some values of (α,β). Interim rationality is satisfied because the prime contractor's expected payoff (with the expectation over the possible values of β) is non-negative for every value of α. See Baron and Besanko (1992) for an interesting analysis of the case in which subcontracting arrangements are made first and *ex post* individual rationality must be satisfied.

Let $\gamma = \alpha+\beta$, the cost of the bundled product. The regulator's policy with vertically integrated supply is a probability of production $Q(\hat{\alpha},\hat{\beta})$ and a payment $t(\hat{\alpha},\hat{\beta})$ given reported costs $(\hat{\alpha},\hat{\beta})$. It is easy to show that incentive compatibility implies that the probability of production can be expressed as a function of γ alone.[8]

Lemma 2: $\gamma = \alpha+\beta$ is a sufficient statistic for the regulator's optimal strategy with vertically integrated production.

Proof: The firm's profit given reports $(\hat{\alpha},\hat{\beta})$ is

$$\Pi(\hat{\alpha},\hat{\beta}|\alpha,\beta) = t(\hat{\alpha},\hat{\beta}) - (\alpha+\beta)Q(\hat{\alpha},\hat{\beta}).$$

Incentive-compatibility requires $\frac{\partial\Pi(\alpha,\beta)}{\partial\alpha} = -Q(\alpha,\beta) = \frac{\partial\Pi(\alpha,\beta)}{\partial\beta}$. These conditions imply that $\frac{\partial Q}{\partial\alpha} = \frac{\partial Q}{\partial\beta}$ and $\frac{\partial t}{\partial\alpha} = \frac{\partial t}{\partial\beta}$, so that $t(\alpha,\beta)$ and $Q(\alpha,\beta)$ are functions only of $\gamma = \alpha+\beta$. Q.E.D.

From Lemma 2, it follows that the regulator's choice reduces to a single-dimensional optimal procurement problem as in Baron and Myerson (1982). Let $h(\gamma)$ denote the density of $\gamma = \alpha+\beta$, $H(\gamma)$ the corresponding distribution function, and $Q^I(\gamma)$ the production rule under vertically integrated supply. The regulator's expected payoff is

$$W^I = \int_0^{A+B} Q^I(\gamma)\left(V - \gamma - \frac{H(\gamma)}{h(\gamma)}\right)h(\gamma)\,d\gamma. \tag{10}$$

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[8] As a result, the solution avoids the complications of multi-dimensional incentive compatibility, as discussed in McAfee and McMillan (1988) and Lewis and Sappington (1988).

Assuming $\frac{H(\gamma)}{h(\gamma)}$ is non-decreasing, an optimal production rule is $Q^I(\gamma) = 1$ if

$$V \geq \gamma + \frac{H(\gamma)}{h(\gamma)},$$

and $Q^I(\gamma) = 0$ otherwise.

Theorem 1: Compare component supply to vertically integrated supply assuming the same production technology for each. The regulator strictly prefers integrated supply if γ is a sufficient statistic for optimal production under component supply.

Proof: Suppose an optimal production rule under component supply is:

$$Q^C(\alpha,\beta) = \begin{cases} 1 & \text{if } \alpha+\beta \leq \bar{\gamma} \\ 0 & \text{otherwise} \end{cases}$$

Case 1: $\bar{\gamma} = A+B$. In this case production under component supply should occur for every value of α and β. This outcome can be implemented by offering firm 1 a price equal to A and firm 2 a price equal to B. The same prices for each component also would assure production under vertically integrated supply, and at the same cost to the regulator. Therefore, the regulator can do at least as well. However, extending the function $g(\beta)$ in the obvious way,

$$h(\gamma) \equiv \int_0^A g(\gamma-\alpha) f(\alpha) d\alpha$$

implies $H(\gamma)/h(\gamma) \rightarrow \infty$ as $\gamma \rightarrow A+B$. Therefore,

$$V-\gamma-\frac{H(\gamma)}{h(\gamma)}<0$$

for γ sufficiently close to $(A+B)$. This implies that the regulator does even better under vertical integration by choosing a production rule with a lower cutoff value of γ.

Case 2: $0 \leq \bar{\gamma} < A+B$ The analysis in Section III shows that $Q^C(\alpha,\beta)$ can be implemented by a subcontracting scheme $\{p(\alpha),q(\alpha)\}$ such that when Producer 1 has cost α it is paid $p(\alpha)$ for production, and Producer 2 is offered a take-it-or-leave-it price $q(\alpha)$. By assumption, γ is a sufficient statistic for production. Therefore it must be that

$$q(\alpha) = \begin{cases} B & \text{if } \alpha < \bar{\gamma}-B \\ \bar{\gamma}-\alpha & \text{if } \bar{\gamma}-B \leq \alpha \leq \bar{\gamma} \\ 0 & \text{if } \alpha > \bar{\gamma} \end{cases}$$

Moreover, incentive compatibility implies that Producer 1's expected profit is:

$$\Pi_1(\alpha) = \begin{cases} \int_{\bar{\gamma}-B}^{A} G(\bar{\gamma}-a)da + \bar{\gamma}-B-\alpha & \text{if } \alpha < \bar{\gamma}-B \\ \int_{\alpha}^{A} G(\bar{\gamma}-a)da & \text{if } \bar{\gamma} \geq \alpha \geq \bar{\gamma}-B \\ 0 & \text{if } \alpha \geq \bar{\gamma} \end{cases}$$

Using the identity

$$\Pi_1(\alpha) = [p(\alpha)-\alpha]G(q(\alpha))$$

we have

$$p(\alpha) = \begin{cases} \alpha + \dfrac{\int_{\alpha}^{A} G(\bar{\gamma}-a)da}{G(\bar{\gamma}-\alpha)} & \text{if } \bar{\gamma} \geq \alpha \geq \bar{\gamma}-B \\ \bar{\gamma}-B + \int_{\bar{\gamma}-B}^{A} G(\bar{\gamma}-a)da & \text{if } \alpha < \bar{\gamma}-B \end{cases}$$

From this it follows that $p(\alpha) + q(\alpha) > \bar{\gamma}$ whenever production takes place. Therefore, the regulator's welfare under component supply must be strictly less than $(V-\bar{\gamma})H(\bar{\gamma})$. However, the regulator can achieve this higher welfare by offering a vertically integrated supplier a bundled price equal to $\bar{\gamma}$. Thus, the regulator strictly prefers vertical integration. Q.E.D.

Vertical integration eliminates the informational equivalent of double marginalization. Under component supply, given that Producer 1 does not know β, there is some probability that β will be low, which would allow Producer 1 to overstate its cost and still produce. A high cost report risks an adverse response from the regulator, but the consequences are borne in part by Producer 2. As a result, under component supply the regulator must pay a substantial information rent to keep each firm from overstating its cost. In the proof, double marginalization appears as a higher payment under component supply conditional on the same production rule for both regimes.

<u>Example 2.</u> Consider the same assumptions as in Example 1, but assume a single firm supplies a bundled product with private information about α and β. If α and β are uniformly distributed over the interval [0,1], γ is distributed according to

$$h(\gamma) = \begin{cases} \gamma & 0 \leq \gamma < 1 \\ 2-\gamma & 1 \leq \gamma \leq 2 \end{cases}$$

$H(\gamma) = \int_0^{\gamma} h(c)\,dc$, so that

$$H(\gamma) = \begin{cases} \frac{\gamma^2}{2} & 0 \leq \gamma < 1 \\ 1 - \frac{(2-\gamma)^2}{2} & 1 \leq \gamma \leq 2. \end{cases}$$

Figure 2 compares W^I and W^C when α and β are distributed uniformly over [0,1]. Note that $W^I > W^C$. If V is 4 or larger, the regulator's optimal policy accepts all offers under component supply, while production is curtailed with positive probability under vertical integration. (For large V, the regulator's probability of acceptance under integrated supply approaches one and W^C approaches W^I.) For small values of V (less than about 2.9), the probability of production under optimal regulation is higher with vertical integration.

If $\alpha+\beta$ is not a sufficient statistic for $Q^C(\alpha,\beta)$, the comparison between vertically integrated supply and component supply is more complicated, and appears ambiguous *a priori*. However, we have not found a counterexample in which the technology is the same for both modes and the regulator prefers component supply, and it is clear that the regulator prefers vertical integration in a wide variety of circumstances. Example

A.1, in the Appendix, illustrates a range of distributional assumptions for which the sufficient statistic property does not hold, yet the buyer is better off under integrated rather than component supply.

V. The regulator's choice of organizational form: multiple IPPs

The regulator is often better off with vertically integrated supply when the distributions of α and β are unchanged by the choice of organizational form. This is not an unreasonable technological assumption if the regulator must choose between a single vertically integrated utility and a single IPP that must sell power to the local utility's grid. However, component supply allows the regulator to benefit from competition in bulk power while recognizing the natural monopoly characteristic of transmission. IPPs may include industrial cogenerators, independent affiliates of other regulated utilities, and unaffiliated suppliers. In several jurisdictions, regulators have solicited bids for bulk power supply from many potential IPPs, with transmission service provided to the winning bidder at a regulated price (see, e.g., New Jersey Board of Public Utilities, 1988). The possibility of competition in bulk power suggests that unbundling transmission and bulk power supply may lower the regulator's expected cost of bulk power.

It is clear from the results so far that (at least in the sufficient statistic case) unbundling supply benefits the regulator only if it leads to a more favorable distribution for one or both of the component products. Suppose the regulator holds an auction for bulk power supply in which *n* IPPs are invited to submit a bid for one unit of bulk power supply. Each IPP's cost is an independent draw of β_i from the distribution function $G(\beta_i)$. The total cost of delivered power for the regulator is the winning bid plus the price of transmission service quoted by the grid. The utility's transmission cost α is assumed independent of the identity of the IPP that supplies power to the grid.

Let $Q(\alpha,\beta)$ denote the probability that the transaction occurs given a realized transmission cost α and a realized minimum transmission cost $\beta = \min\{\beta_1,\beta_2,...\beta_n\}$. Let $b(\beta)$ denote the winning bid, i.e. the payment to the low cost bidder if production takes place. If $b(\beta_i)$ is an equilibrium bidding strategy, then, following Laffont and Tirole (1987), McAfee and McMillan (1987), Riordan and Sappington (1987), and Dasgupta and Spulber (1989), the expected profit of an IPP, conditional on a cost β_i and a bid $b(\hat{\beta}_i)$, is

$$\bar{\Pi}_i(\hat{\beta},\beta_i) = Y(\hat{\beta})[b(\hat{\beta})-\beta_i][1-G(\hat{\beta})]^{n-1}$$

where $Y(\hat{\beta}) = \int_0^A Q(\alpha,\hat{\beta})f(\alpha)d\alpha$ as before. Incentive compatibility requires that $\Pi_i(\beta_i) \equiv \bar{\Pi}_i(\beta_i,\beta_i)$ satisfy $\frac{\partial \Pi_i(\beta)}{\partial \beta} = -Y(\beta)[1-G(\beta)]^{n-1}$. Therefore, imposing $\Pi_i(B) = 0$ to satisfy individual rationality, we have

$$\Pi_i(\beta) = \int_\beta^B Y(x)[1-G(x)]^{n-1}dx. \tag{11}$$

Using (11), integrating by parts and simplifying, the regulator's expected welfare can be written as

$$W^{Cn} = \max_{Q(\alpha,\beta)} \int_0^A\int_0^B Q(\alpha,\beta)[V-\alpha-\beta-\frac{F(\alpha)}{f(\alpha)}-\frac{G(\beta)}{g(\beta)}]f(\alpha)j(\beta)\,d\alpha\,d\beta, \tag{12}$$

where $j(\beta) = ng(\beta)[1-G(\beta)]^{n-1}$ is the density function for the lowest value of β. The optimal production rule is the same as in the case of $n = 1$. Production takes place if and only if $V \geq \alpha+\beta+\frac{F(\alpha)}{f(\alpha)}+\frac{G(\beta)}{g(\beta)}$. As n gets large this maximum value function converges to

$$\max_{Q(\alpha)} \int_0^A Q(\alpha)[V-\alpha-\frac{F(\alpha)}{f(\alpha)}]\, f(\alpha)\, d\alpha,$$

because the regulator becomes virtually certain that the low β_i is nearly zero. This observation leads to the following.

Theorem 2 : Suppose β_i, $i=1,..n$, are i.i.d. random variables, each with density $g(\beta)$ on $[0,B]$, and α is an independent random variable with density $f(\alpha)$ on $[0,A]$. Compare a single vertically integrated firm with cost $\alpha+\beta$, to component production where the regulator deals with a single firm with cost α to supply the first component and n different firms with respective costs β_i, $i = ,...,n$ that compete to supply the second component. For sufficiently large n, the regulator is better off with component production.

Proof: Define the convex function $\psi(x) = max\{0,x\}$. If, under vertical integration, the regulator knew the value of β with certainty, the regulator's payoff would be

$$W(\beta) = \int_0^{A+B} \psi((V-\gamma)f(\gamma-\beta) - F(\gamma-\beta))\, d\gamma,$$

where $f(\alpha)$ and $F(\alpha)$ are extended outside $[0,A]$ in the obvious way. By Jensen's inequality,

$$\int_0^B W(\beta)g(\beta)d\beta > W'.$$

As n increases without limit, the regulator's expected payoff under component supply converges to $W(0)$. Since $W(\beta)$ is decreasing, we conclude that $W(0) > W'$. Q.E.D.

Competitive component supply dominates vertical integration if the number of bidders is sufficiently large, but the theorem does not say how much competition is sufficient for the regulator to prefer component supply. Although the answer would depend on specific functional forms, the following example suggests that only modest levels of competition may be adequate for component supply to be the preferred organizational form.

Example 3. Assume α and β are each distributed uniformly over [0,1]. Components are supplied separately, with competitive bidding by n suppliers for component β. Then

$$\frac{F(\alpha)}{f(\alpha)} = \alpha; \quad \frac{G(\beta)}{g(\beta)} = \beta; \quad j(\beta) = n(1-\beta)^{n-1}$$

As in Example 1, under component supply the critical value of γ above which the regulator would refuse supply is $\bar{\gamma} = \min[\frac{V}{2}, 2]$. Example 2 describes the optimal policy for the vertically integrated regime. Direct calculation reveals that only modest levels of competition are sufficient for the superiority of component supply. If there are three or more firms, component supply is preferred by the regulator to vertical integration for any value of the delivered product.

This comparison of vertical integration and component supply assumes that the regulated, vertically integrated firm would pursue only one technique (plant) for the β component (corresponding to a single draw from the distribution $G(\beta)$), while deregulation would result in several competing alternatives (corresponding to n draws from $G(\beta)$). As a result, the comparison is potentially biased against vertical integration, because it assumes that the vertically integrated firm does not have the benefit of multiple draws to determine the lowest cost source of supply.

A derivation of the optimal structure of production with both competition and vertical integration is beyond the scope of this paper. However, as a contrast to the case where the vertically integrated firm operates only one plant, consider the case where the same technology (the same number of plants, n) is used under both regimes. With the same technology in both regimes, Theorem 1 might suggest that the regulator would prefer vertical integration. Although this is possible, in other situations component supply may be preferred because the regulator benefits from horizontal competition. In a limiting situation where the cost of the α component is known, under component supply the regulator would compare competition among n firms, each with density $g(\beta)$, to regulation of a single firm with density $j(\beta)$ under integrated supply. It can be shown that the regulator would prefer component supply in this situation. However, when α is not known with certainty, the integrated regime may dominate. This result is summarized in the following theorem.

Theorem 3 : Suppose β_i, *i=1,..n, are i.i.d. random variables, each with density* $g(\beta)$ *on* $[0,B]$, *and* α *is an independent random variable with density* $f(\alpha)$ *on* $[0,A]$. *Let* $\beta = \min\{\beta_1,\ldots,\beta_n\}$. *Compare vertically integrated production with cost* $\alpha+\beta$ *to component production where a single firm with cost* α *supplies the first component and n different firms with respective costs* β_i, $i = ,\ldots,n$ *compete to supply the second component. For* $n \geq 2$, *the regulator is better off with component supply if A is sufficiently small.*

Proof: The proof is a variant of the prime/sub-contractor methodology used to prove Theorem 1 and appears in the Appendix.

The logic of the proof is straightforward. Horizontal competition among *n* IPPs allows the regulator to implement an outcome with lower information rents for the second component. The regulator's optimal production policy under vertical integration is feasible under competition (see, e.g. Dasgupta and Spulber (1987)), and to the extent that optimal policies differ, the regulator is better off with competition. However, competition denies the regulator the informational advantage of vertical integration in the revelation of total cost (i.e. the elimination of double-marginalization). If the regulator's uncertainty about the first component is sufficiently small, the benefits of competition in the second component outweigh the informational value of vertical integration. Note that the logic of the proof of Theorem 3 does not rely on a specific assumption about the number of plants operated by the vertically integrated firm, although competition is relatively more attractive when the integrated firm operates fewer plants.

Consistent with Theorem 3 is the result that in a wide range of circumstances, the informational advantages of vertical integration may dominate the horizontal competition afforded by component supply. This is illustrated by the following example.

Example 4. Assume α is uniformly distributed over $[0,A]$ and β_i, $i = 1,\ldots,n$ are distributed uniformly and independently over [0,1]. Under component supply, as in Example 3 there is competitive bidding by n firms for production of the second component. Under vertically integrated supply, it is common knowledge that the regulated firm operates n plants, so that the relevant β for integrated supply is $\min\{\beta_1,\ldots,\beta_n\}$. Figure 3 shows the critical values of A for which the regulator is indifferent between to two regimes, assuming different values of V. For values of A above the critical values the regulator would prefer vertically integrated supply. Larger values of A correspond to greater potential information rents and relatively smaller gains from horizontal competition over the cost component β, so that vertical integration becomes more attractive to the regulator.

VI. Concluding Remarks

Our results show that dissolution of a regulated service into two separate, regulated components can raise the information costs of regulation. In a broad range of circumstances, it is cheaper in expected value to elicit truthful information about the cost of both components as a bundled product than to elicit information about each component separately. The intuition is related to the problem of double marginalization when firms produce complementary products. Each component supplier ignores the consequences of a high cost report on the profits of the supplier of the complementary product, while the integrated producer internalizes this effect. Although under component supply, each producer is disciplined by the possibility that the supplier of the complementary product has a high cost, our analysis shows that when total cost is a sufficient statistic for the regulator's optimal policy in both supply regimes, the regulator is better off in expected value under vertically integrated supply.

The higher information costs from component supply can be mitigated if dissolution of the regulated service permits increased competition in one (or both) of the components. This is a main motivation for recent proposals to allow greater access to transmission by independent power producers and non-local utility suppliers. Pricing of transmission services has been a key issue in the policy debate. The current practice of the Federal Energy Regulatory Commission requires most firm transmission access to be priced at fully embedded cost (Spiewak and Weiss, 1991). However, the opportunity cost of transmission can be much more or much less than its embedded cost. Critics of FERC transmission policy want more flexible access pricing, arguing that pricing at embedded cost forecloses some transactions that would be efficient and over-rewards utilities for other transactions.

Our results generally support the appeal for flexible transmission pricing. Optimal pricing is a function of the utility's reported opportunity cost. The regulator may moderate information costs by imposing on the utility a risk that access would be denied if the reported cost is high, and that the utility as well as the component energy supplier would suffer as a consequence. Our results also show that if the regulator's value of service is sufficiently large, the optimal policy is to price transmission at its highest opportunity cost and to accept all proposals. Inflexible access pricing rules can be second-best optimal regulatory policies when the value of service is large, although pricing has to err on the side of giving away positive rents to the owner of the transmission resource.

The analysis presumes the regulated firm is profit-maximizing and bears the opportunity cost of transmission usage. In many jurisdictions, the benefits and costs of purchased power, a key aspect of transmission opportunity costs, are passed through to consumers. This does not mean, however, that regulated firms are insensitive to this component of their operations. Regulatory lag may allow firms to benefit from savings in purchased power, and excessive operating costs can jeopardize allowed returns in future rate hearings. Nonetheless, it would be useful to embed the problem of access pricing in the larger context of second-best optimal utility regulation with endogenous managerial effort (as in Laffont and Tirole, 1987). This would permit a direct analysis of the influence of utility usage of transmission capacity on cost recovery in an optimal regulatory environment.

Our analysis also presumes the regulator compares the performance of alternative organizational modes *ex ante*, before gaining any knowledge of realized costs. However, in many circumstances, including those surrounding bulk power transactions, it might be feasible for the regulator to condition organizational decisions on the cost reports of the public utility and the IPPs. Endogenizing the choice of organizational mode in this way is a topic for future research.

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Appendix A

Example A.1: *Comparison of component supply and vertical integration when γ is not a sufficient statistic for second-best optimal regulation with component supply.*

Assume $F(\alpha) = \alpha^s$ on [0,1], $G(\beta) = \beta^t$ on [0,1], $|t-s| \leq 1$. Assume w.l.o.g. that $t \geq s$. If $t = s$, then the sufficient statistic property is satisfied and Theorem 1 applies. So consider the case $t - s > 0$. Define

$$A_o = \max\{0, \frac{V-(1+t)}{1+s}\}$$

$$A^o = \max\{1, \frac{V}{1+s}\}$$

Then

$$q(\alpha) = \begin{cases} 0 & \text{if } A^o \leq \alpha \\ \dfrac{V-(1+s)\alpha}{1+t} & \text{if } A_o \leq \alpha \leq A^o \\ 1 & \text{if } \alpha \leq A_o \end{cases}$$

It follows that $\alpha + q(\alpha)$ is increasing whenever $q(\alpha) > 0$.

If $A_o \leq \alpha \leq A^o$, then

$$p(\alpha)+q(\alpha) = \frac{(2+s)V}{(1+s)(1+t)} + \frac{(t-s-1)\alpha}{1+t} - \frac{[V-(1+s)A^o]^{1+t}}{(1+s)(1+t)[V-(1+s)\alpha]^t}$$

For $\alpha \leq A_o$, $p(\alpha) + q(\alpha)$ is constant. Therefore, $t - s \leq 1$ implies $p(\alpha) + q(\alpha)$ is decreasing whenever $q(\alpha) > 0$. Suppose the buyer offered a take-it-or-leave-it price $[p(A^o) + q(A^o)]$ to a vertically integrated supplier. Production takes places at least as often and at a lower total price. Therefore, the buyer is better off than with component supply.

Appendix B

Proof of Theorem 3.

Let $\bar{\gamma}$ be the critical value above which the regulator would refuse production under integrated supply and assume $B \geq \bar{\gamma} > A$ (the case where $B < \bar{\gamma}$ is similar). Suppose each of the n IPPs "bids" a cost report $\hat{\beta}$. The winning IPP becomes the prime contractor, with the public utility providing transmission service as a subcontractor. The lowest bid from an IPP determines a mechanism $\{p(\beta), q(\beta)\}$, where $p(\beta)$ is the subcontracting price and $q(\beta)$ is the payment to the winning IPP if production takes place. Production takes place if the utility accepts $p(\beta)$. If follows that $\bar{\gamma}$ is implemented if

$$p(\beta) = \begin{cases} \bar{\gamma} - \beta & \text{if } \bar{\gamma} \geq \beta \geq \bar{\gamma} - A \\ A & \text{if } 0 \leq \beta < \bar{\gamma} - A \end{cases} \tag{A.1}$$

Assuming truthtelling by rival IPPs, an IPP of type β who bids $\hat{\beta}$ earns expected rents

$$\bar{\Pi}_i(\beta, \hat{\beta}) = F(p(\hat{\beta}))[q(\hat{\beta}) - \beta][1 - G(\hat{\beta})]^{n-1}. \tag{A.2}$$

Letting $\Pi_i(\beta) \equiv \bar{\Pi}_i(\beta, \hat{\beta})$, incentive compatibility implies

$$\frac{\partial \Pi_i(\beta)}{\partial \beta} = -F(p(\beta))[1 - G(\beta)]^{n-1},$$

and using (A.1) and (A.2) along with individual rationality gives

$$\Pi(\beta) = \begin{cases} \int_{\beta}^{\bar{\gamma}} F(\bar{\gamma}-b)[1-G(b)]^{n-1}db & \text{if } \bar{\gamma}\geq\beta\geq\bar{\gamma}-A \\ \int_{\bar{\gamma}-A}^{\bar{\gamma}} F(\bar{\gamma}-b)[1-G(b)]^{n-1}db + \int_{\beta}^{\bar{\gamma}-A}[1-G(b)]^{n-1}db & \text{if } \beta<\bar{\gamma}-A \end{cases}$$

from which it follows that

$$q(\beta) = \begin{cases} \beta + \dfrac{\int_{\beta}^{\bar{\gamma}} F(\bar{\gamma}-b)[1-G(b)]^{n-1}db}{F(\bar{\gamma}-\beta)[1-G(\beta)]^{n-1}} & \text{if } \bar{\gamma}\geq\beta\geq\bar{\gamma}-A \\ \beta + \dfrac{\int_{\bar{\gamma}-A}^{\bar{\gamma}} F(\bar{\gamma}-b)[1-G(b)]^{n-1}db + \int_{\beta}^{\bar{\gamma}-A}[1-G(b)]^{n-1}db}{[1-G(\beta)]^{n-1}} & \text{if } \beta<\bar{\gamma}-A \end{cases} \tag{A.3}$$

Observe that $p(\beta) + q(\beta)$ is less than

$$\zeta(\beta) = \min[\bar{\gamma}, \beta+A] + \frac{\int_{\beta}^{\bar{\gamma}}[1-G(b)]^{n-1}db}{[1-G(\beta)]^{n-1}} \tag{A.4}$$

Moreover, for a given $\bar{\gamma}$, $0<\bar{\gamma}\leq B$,

$$\lim_{A\to 0} \zeta(\beta) = \bar{\gamma} - \int_{\beta}^{\bar{\gamma}}\left(1 - \frac{[1-G(b)]^{n-1}}{[1-G(\beta)]^{n-1}}\right)db \tag{A.5}$$

which is strictly less than $\bar{\gamma}$. Therefore, by continuity, if A is sufficiently close to zero, it must be that $p(\beta)+q(\beta) < \bar{\gamma}$, implying that the regulator can implement the same production rule under component supply at a lower cost. Q.E.D.

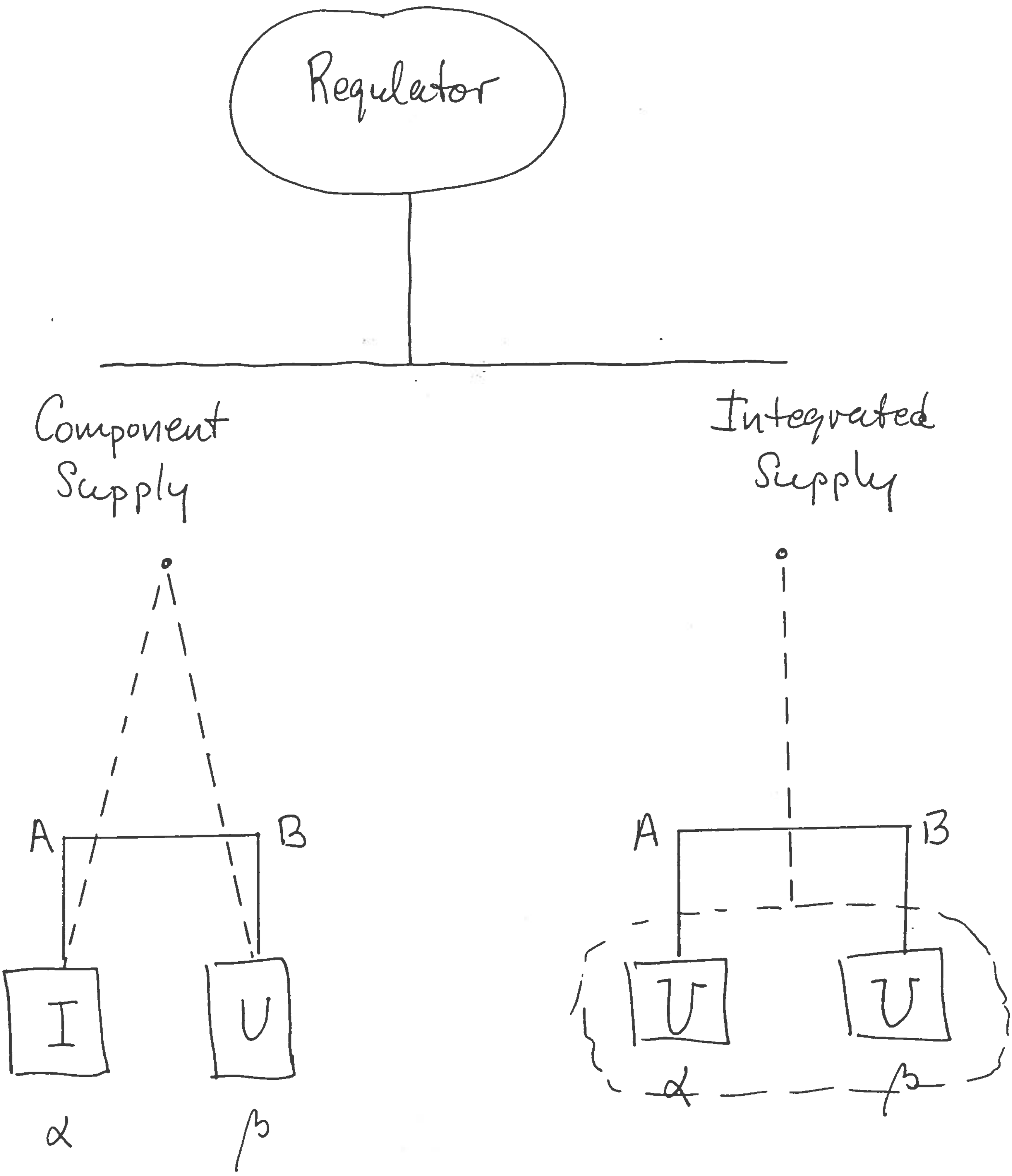
Regulator
Component Supply
Integrated Supply
A
B
I
U
α
β
A
B
U
U
α
β

Figure 1

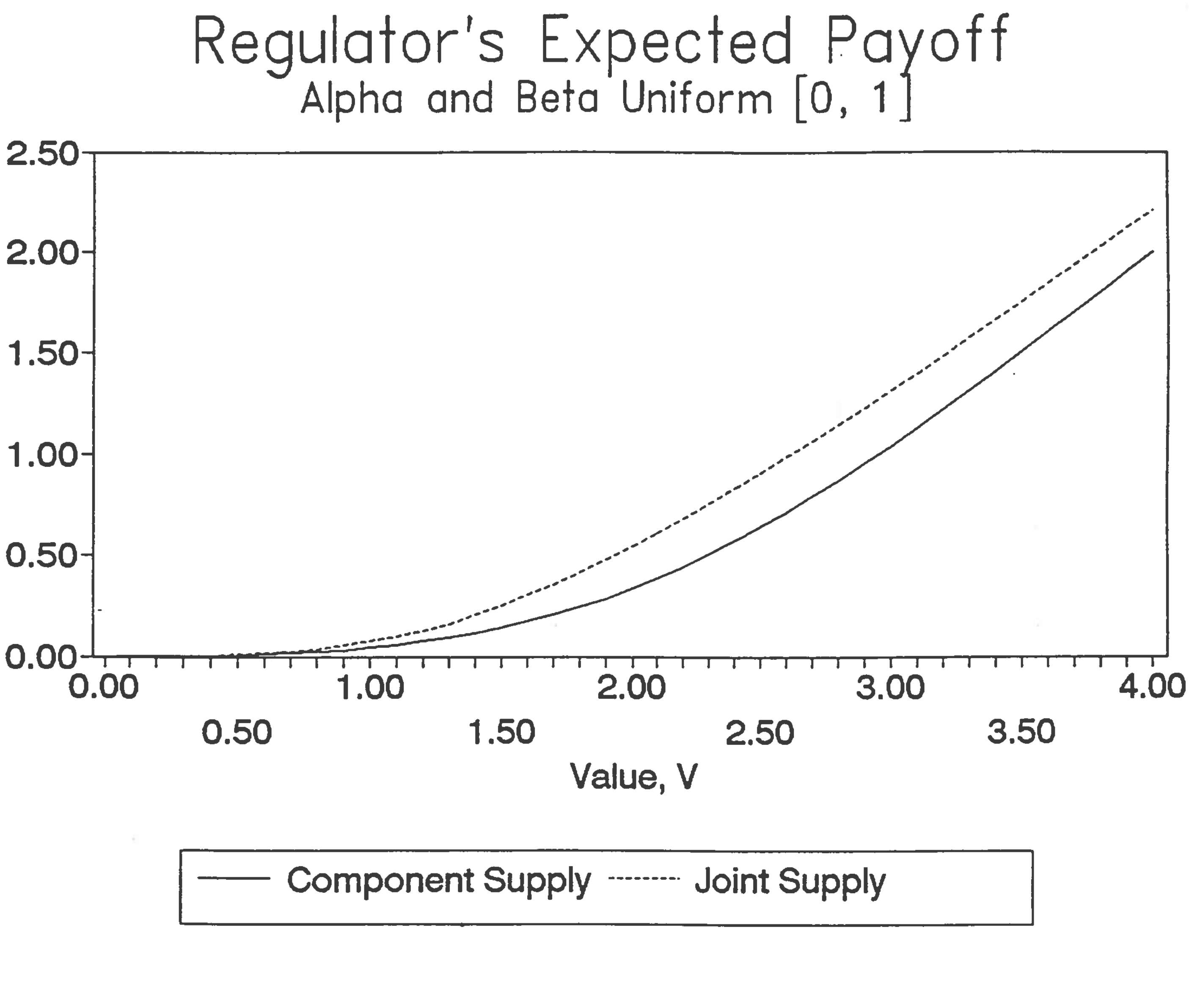
Regulator's Expected Payoff
Alpha and Beta Uniform [0, 1]
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Value, V
Component Supply
Joint Supply

Figure 2

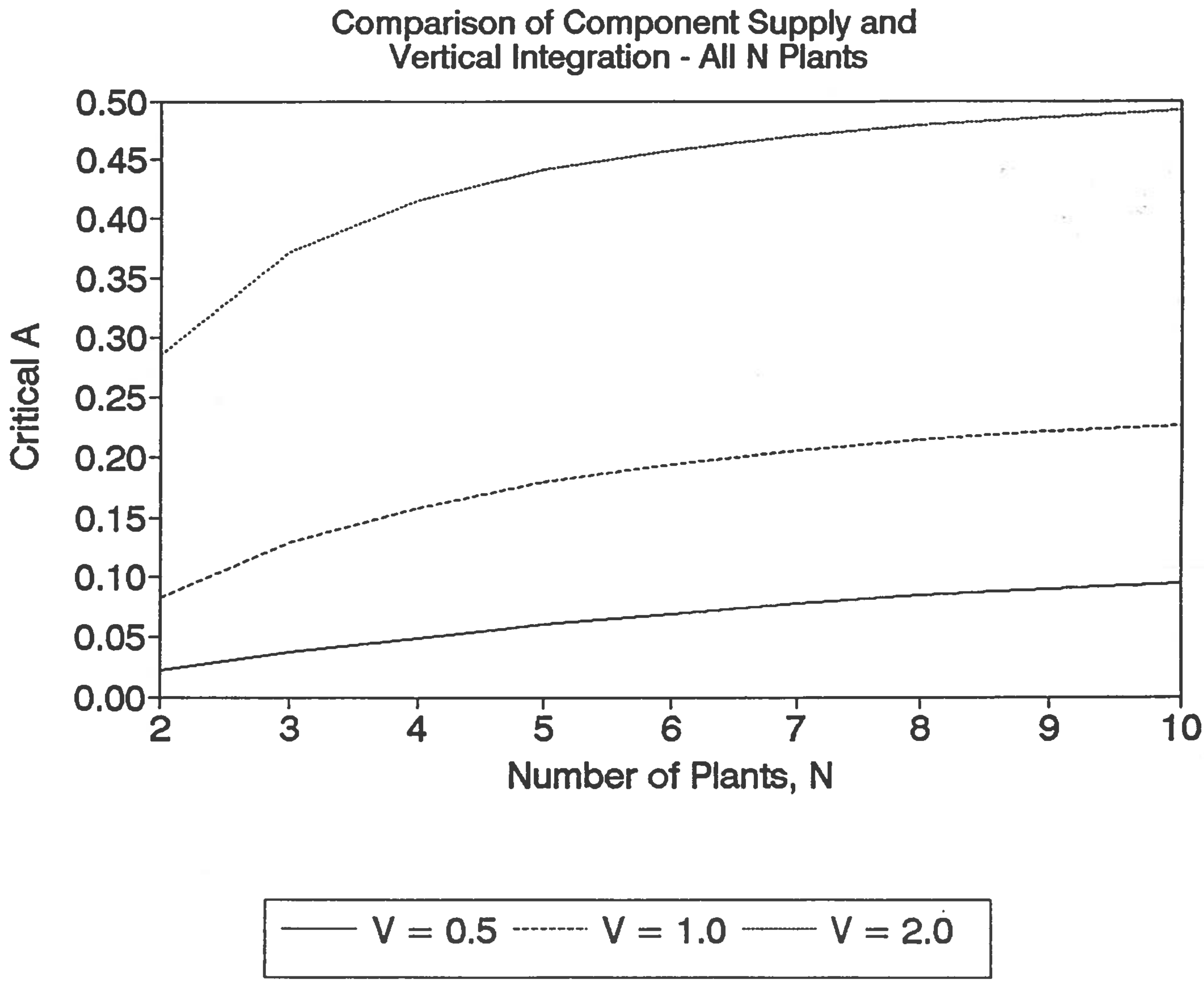
Comparison of Component Supply and
Vertical Integration - All N Plants
Critical A
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
2
3
4
5
6
7
8
9
10
Number of Plants, N
V = 0.5
V = 1.0
V = 2.0

Figure 3