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Endogenous Regulatory Constraints and the Emergence of Hybrid Regulation

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Abstract Models of public utility regulation are often framed, alternatively, as rate-of-return or price-cap regulation. In practice, however, regulators have increasingly adopted a variety of hybrid regulatory constraints that embody elements of both these, and other, regulatory forms. In this paper, we draw upon elements of both the positive economic theory of regulation and standard efficiency-based economic analysis of regulation to develop a model that endogenously yields hybrid regulatory constraints as a regulatory optimum. In this context, the paper further demonstrates that a commonly observed side payment–profit sharing–enhances regulator welfare. The results provide a plausible basis for understanding the pattern of modern regulatory constraints.

Keywords Endogenous regulation · Rate-of-return · Profit sharing

JEL Classification L51 · L97

1 Introduction

The nearly simultaneous publication of two papers in 1962 set the stage for much of the economic research on regulation for the next four decades. First, Averch and Johnson (1962) (AJ) are credited with demonstrating that rate-of-return regulation,

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even if (specifically if) practiced in textbook fashion, would result in the inefficient adoption of inputs by the regulated firm. Subsequently, a host of economic research has critically evaluated the efficiency properties of regulation.[1] Second, Stigler and Friedland (1962) opened an equally important, but fundamentally different critique of regulation with the publication of their seminal paper "What can regulators regulate?" Like the Averch–Johnson paper, the Stigler–Friedland paper launched an extensive literature.[2] While each of these two, principally disparate, literatures tends to inform the other, there are few direct attempts to employ the core elements of each to advance our fundamental knowledge of the economic characteristics and outcomes that are likely to emerge through regulation.[3]

In this paper, we attempt such a synthesis in order to address an important question that has to this point largely been seen as a precursor to economic analysis. Namely, we draw upon both the positive economic theory of regulation developed by Stigler and Friedland and the formal modeling of regulation initiated by Averch and Johnson to develop a model in which the choice of regulatory constraints is endogenously determined. Importantly, the model yields a selection of regulatory constraints that is neither pure rate-of-return regulation, as analyzed by AJ, nor pure price caps, as has been the subject of more recent economic research of regulation.[4] Rather, consistent with the pattern of modern regulation of public utilities in the United States, the regulatory optimum is shown likely to involve a hybrid of these regulatory constraints.

The paper proceeds as follows. Section 2 provides a background discussion that highlights the evolution in both theory and practice of the principal regulatory constraints facing public utilities in the United States. Next, in Sect. 3, we provide a model in which the regulator faces political pressure in response to three distinct measures: the utility's profit level, consumer welfare as a function of price, and the utility's rate of return. We demonstrate that the optimal rate-setting regime will be a hybrid form of price-cap and rate-of-return regulation. Along the way, we explore the regulator's political support problem in input space, which allows us to extract interesting efficiency implications—a subject of long standing interest dating back to AJ. Section 4 introduces the possibility of regulator-mandated rent transfers from the firm to customers in the form of profit sharing. The results indicate that profit sharing may not only serve to enhance efficiency but may also increase political support for the regulator relative to the adoption of either "pure" or simple hybrid regulatory regimes. Section 5

[1] See e.g., Baumol and Klevorick (1970), Zajac (1970), Bailey and Coleman (1971), Bailey (1973) and subsequent literature. For comprehensive surveys, see Joskow and Rose (1989) and Armstrong and Sappington (2007).

[2] See e.g., Stigler (1971); Posner (1971, 1974); Peltzman (1976); Becker (1983); Noll (1989); Laffont and Tirole (1991), and Beard et al. (2003). That this literature traces its lineage to Stigler and Friedland (1962) is pointed out in Peltzman (1976): "[w]hat Stigler (1971) accomplished in his *Theory of economic regulation* was to crystallize a revisionism … that he had helped launch in his and Claire Friedland's work on electric utilities. The revisionism had its genesis in a growing disenchantment with the usefulness of the traditional role of regulation in economic analysis as a *deus ex machina* which eliminated one or another unfortunate allocative consequence of market failure." Peltzman (1976, p. 211).

[3] For exceptions, see Evans and Garber (1988), Laffont and Tirole (1991).

[4] For comprehensive reviews of this literature on price cap regulation and the related work on "incentive regulation," see Lyon (1994), Vogelsang (2002), Crew and Kleindorfer (2002), Armstrong and Sappington (2007).

then offers a discussion of our results relative to the evolving normative literature on optimal regulatory designs under information asymmetries. Finally, Sect. 6 concludes and identifies promising areas of extensions to the model presented here.

2 The Evolution of Regulatory Constraints

2.1 In Theory

The theoretical design of efficient regulatory mechanisms has a rich lineage and has been the subject of numerous papers.[5] Less well studied has been the investigation of how specific regulatory constraints that exist may arise. Baron and Taggart (1980) observe that despite its known inefficiencies, rate-of-return regulation may arise because surplus maximizing regulators lack sufficient information on the firm's production and/or cost function to be able to establish first- or second-best prices. As noted by Baron (1989) in his survey of the design of regulatory mechanisms, however, this approach may be improved by asking if "the representation of regulation in the Averch–Johnson model would arise endogenously as the optimal form of regulation when either information is incomplete or observability is limited."

In this spirit, Besanko (1984) develops a model in which a consumer-surplus-maximizing regulator designs a regulatory policy in a world in which the firm enjoys asymmetrically greater information about its labor requirements than does the regulator. Because the firm's capital choice provides information to the regulator regarding the firm's underlying technology, the regulator is led to adopt a rate-of-return regulatory regime.[6] Thus, while adopting a rate-of-return constraint necessarily engenders an AJ overcapitalization, regulators nonetheless adopt this regulatory constraint because it provides a means by which they may ensure that the capital investment decisions provide them with informational value regarding the firm's technology. In this model, then, rate-of-return regulation arises as a consequence of asymmetric information.

While Besanko provides an important step from the normative design of optimal regulatory mechanisms to a positive analysis of endogenous mechanism by which rate-of-return regulation may arise, several promising avenues of exploration remain. Among these, perhaps the most prominent is to explore the potential for particular regulatory constraints to emerge as a consequence of an interest-group specification of the regulator's objective function. That is, could the emergence of rate-of-return regulation or other forms of regulatory constraints arise as endogenously determined optima when we allow for interest-group politics to influence regulators' welfare?

Peltzman (1976) generalization of the economic theory of regulation opened the door to just such an analysis. Peltzman, along with Stigler (1971) before him, developed a positive model of regulator behavior built upon the proposition that regulators will not serve a single social interest (e.g., maximization of consumer or total surplus), but rather their own, narrow, but multifaceted objectives driven by "the dominance of

[5] See, e.g., Baron (1989), Armstrong and Sappington (2004, 2007).

[6] The optimal rate-of-return authorized is shown to be a decreasing function of the amount of capital employed.

political pressure for redistribution [of economic welfare] on the regulatory process."[7] Subsequently, Becker (1983) articulated a regulatory equilibrium as a product of competing interest groups, each of which curries regulatory favors and "pays" for these favors with votes, income, or jobs for regulators. Equilibrium price levels are determined by the relative strengths of the various interest groups that may influence the regulator. While shedding considerable light on the price level(s) that are likely to emerge from the regulatory process, however, the role (if any) of rate-of-return constraints is not explicitly addressed in this literature.

The potential for rate-of-return constraints to arise endogenously in an interest group setting was, however, addressed by Evans and Garber (1988). They develop a model in which regulators seek to design regulatory constraints for the firm that advance the interests of the regulator. The regulator, however, is subject to interest group pressures from consumers and firms. These pressures result in an objective function for the regulator, whose arguments include price, profits, and the regulated firm's rate-of return. They find that a regulator with this objective function will impose rate-of-return regulation on the firm. They further demonstrate that this political equilibrium necessarily entails the standard AJ inefficiencies brought on by overcapitalization.

2.2 In Practice

Turning to the practice of regulation, rate-of-return (ROR) regulation served as the dominant form of regulation of public utilities in the United States throughout the 20th century. This was especially true in 1962 when Averch and Johnson demonstrated that rate-base, rate-of-return regulation would lead to systematic biases in the input choices of firms subject to this regulation. Even today, some 47 years after the work of AJ, rate-of-return regulation remains a prominent, though now not ubiquitous, regulatory regime. Is the loyalty toward rate-of-return regulation best explained by Besanko (that regulators maintain rate-of-return regulation because it permits regulators to overcome information asymmetries), by Evans and Garber (that rate of return regulation is the result of an interest group equilibrium), or by an alternative?

These questions are made all the more intriguing by the emergence of alternative regulatory constraints. As early as the late 1970s price cap regulation (PCAP) began to garner attention in the academic arena and by the 1990s was increasingly adopted by regulators.[8] Importantly, the academic literature demonstrated that, while certainly only a "good"—not perfect—regulatory regime, price cap regulation did act to eliminate the capital input distortion associated with ROR regulation.[9]

Despite this ability of PCAP regulation to eliminate the capital input bias associated with ROR regulation, regulators have not ubiquitously embraced this regulatory alternative to ROR. Indeed, a recent survey of regulatory regimes in the US telecommunications industry providers recently concluded that regulators are still "transitioning"

7 Peltzman (1976, p. 211).

8 See, e.g., Littlechild (1983, 1986), Pint (1992), Liston (1993), Lyon (1994), Crew and Kleindorfer (1996) and Armstrong and Sappington (2007).

9 See, e.g., Schmalensee (1989).

from ROR to alternative forms of regulation.[10] Not only has the transition from ROR to PCAP taken a considerable period, but increasingly regulators are adopting hybrid forms of regulation that embody elements of both ROR and PCAP. As noted, "An increasing tendency among states is to apply different regulatory regimes … combining price caps with ROR. As of September 2004, eleven states were using a combination of regimes to regulate the [local exchange telephone companies] providing service in their territories."[11]

Moreover, even in regulatory regimes that nominally are "price cap" or "rate of return", the practicalities of these regimes quite often involve elements of the other. For example, as Johnson (1994) has observed:

> …price-cap regulation can best be regarded as a loose form of rate-of-return regulation with a formal time lag. Price-cap regimes typically include a periodic review of performance (including the historic rate of return) and an adjustment in the formula to bring the projected rate of return in line with what regulators would regard as just and reasonable.

And even earlier, Joskow (1974) noted that, within the framework of ROR regulation, price constraints may emerge as the most operatively binding constraint in the presence of regulatory lag. Consequently, as observed in practice, regulatory regimes that are labeled, alternatively, "rate-of-return regulation" and "price cap regulation" display elements of both regulatory constraints. Thus, many regulated firms now effectively operate under a hybrid regulatory regime with elements of both price and rate of return controls.[12]

In the next section, we provide a model that is consistent with the emergence of the imposition of these hybrid regulatory constraints.

3 The Regulator's Choice Model

The principal heuristic explanation for the failure of regulators to adopt alternative, more efficient regulatory constraints stems from the positive political economy research initially spawned by Stigler and Friedland. Indeed, the rather incontrovertible conclusion that regulatory outcomes and the regulatory constraints that generate them—are the product of the demand and supply for regulatory benefits is well

[10] Perez-Chavolla (2007, p. 1). The pace of this transition appears to vary across industries, with a more pronounced tendency away from (formal) earnings sharing plans in the telecommunications industry relative to other industries such as electricity. This variance may be attributable to the more advanced nature of competitive inroads in telecommunications relative to other traditional public utilities.

[11] Perez-Chavolla (2004, p. iv). Also see Schmidt (2000) for details on the hybrid features of alternative regulation schemes across multiple industries.

[12] For another example, see Australian energy regulator "AER" (2005) describing the details of the revenue cap scheme utilized for electric transmission service in which a "regulatory period" of at least 5 years is adopted, the transmission service provider "must submit a revenue cap application by 1 April of the penultimate year of the regulatory period", and "[t]he AER will determine a WACC that provides a fair and reasonable rate of return applicable to [transmission service providers]." (p. 20) Under a similar scheme in the United Kingdom, "Ofgem sets the cost of capital which is the allowed rate of return the companies can recoup when they invest in their networks." Ofgem (2006, p. 2)

established. Less well established are the details of how and why regulators may establish particular regulatory instruments.[13]

The regulatory environment modeled below includes an investor-owned profit maximizing firm with an exclusive monopoly franchise providing a single service to customers in a specified geographic area (hereafter, the "firm" or "utility").[14] The regulatory agency (hereafter, "regulator") has autonomous authority to control the conduct and performance of the utility. The firm and customers exert political pressure or support in an attempt to influence the regulator's decisions. The regulator's objective is the maximization of political support, i.e., regulator welfare is a monotonic function of political support. Furthermore, customers' information is limited to price and rate of return, with no information regarding the firm's underlying technology or technology options.[15]

We begin with a general model specification that is consistent with that of Peltzman (1976), in which the firm's political support (or pressure) is a positive function of economic profit and customers' political support is a positive function of consumers' surplus (or a negative function of price level). Political support from the regulated firm would be highest when economic profit is at the unconstrained maximum and political support from customers would be highest at zero economic profit.[16] *Marginal* political support from the firm, however, is highest when profit is zero, and *marginal* political support from customers is highest when profit is at the unconstrained maximum. Marginal political support related to either group is diminishing as the regulator moves toward the interest group's optimum.[17] As emphasized by Peltzman (p. 217):

> Thus we have an important first principle of regulation: even if a single economic interest gets all the benefits of regulation, these must be less than a perfect broker for the group would obtain. The best organized cartel will yield less to the

[13] Crew and Kleindorfer (2001) critique "the oft-cited problem in incentive regulation of assuring what economic theorists refer to as regulatory commitment." They emphasize the importance of constraints on regulatory commitment to price cap regulation such as unacceptably low profits threatening the viability of the regulated firm and unacceptably high profits drawing public pressure from consumer advocates. Crew and Kleindorfer, therefore, encourage the incorporation of such regulatory commitment constraints into the normative modeling of alternative regulatory mechanisms and related firm incentives. Their paper provides some motivation for our work here in that we endogenously derive the characteristics of mechanisms that regulators will tend to adopt, *ex ante*, in recognition of the political pressures they face. These characteristics include a lack of commitment to pure price cap regulation and the tendency to adopt hybrid forms of regulation.

[14] The model presented here involves the regulation of a pure monopolist. An interesting extension, but one beyond the scope of the present paper, is to consider the regulatory optima akin to those derived here, but in the presence of competition.

[15] In making this assumption, we continue the standard assumption of information asymmetries among the relevant parties to the regulatory process. Our focus here is, however, on consumers that are asymmetrically under-endowed with information regarding the operating characteristics of the firm. This parallels, we believe quite plausibly, the frequently adopted assumption that regulators are asymmetrically under-endowed regarding the firm's technology.

[16] Negative economic profit serves neither group in the long run because of bankruptcy and possible discontinuance of service.

[17] This assumption is attributed to Stigler (1971).

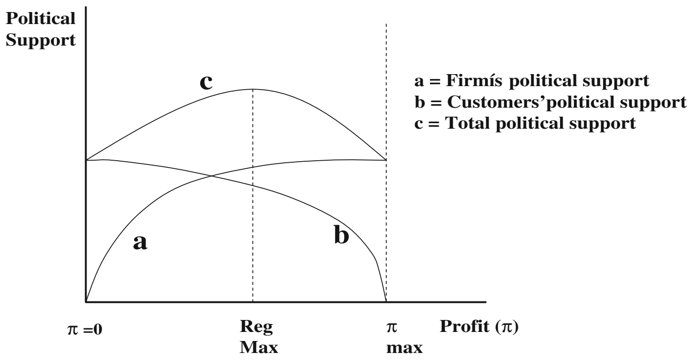

Fig. 1 Peltzman's first principle of regulation

> membership if the government organizes it than if it were (could be) organized privately. This principle is independent of organization or campaigning costs, but rests on the heed the political process must pay to marginal position.

Peltzman's "first principle of regulation" is depicted in Fig. 1, below. At the point of unconstrained maximum economic profit (πmax) political support from the firm is highest, marginal support from the firm is zero, but marginal political support from customers for a change is highest. At the point of zero economic profit ($\pi = 0$), political support from customers is highest and marginal support from customers has diminished to zero because price (and rate of return) are at their lowest feasible level. Marginal support for change from the firm's perspective, however, is highest when $\pi = 0$. Therefore, Peltzman's model results in an interior solution (Reg max) in which economic profit is greater than zero but less than the unconstrained maximum.

Our inquiry now moves beyond that of Peltzman in that we use his general framework to derive endogenously the type of regulatory constraints (price-cap versus rate-of-return constraints) one would expect to see in practice. Before proceeding with our inquiry, however, we modify the general model specification to invoke a premise that political support from customers is inversely related to the utility's rate of return; that is, at any given price level in which $\pi > 0$, political support from customers would marginally increase (or pressure from customers would marginally decrease) if rate of return was lower.[18] The inclusion of this premise is a natural extension of the assumption that customers have no information regarding underlying technology or the firm's production function. As a consequence, consumers focus on the more readily observable rate of return, which, in turn, then becomes a key indicator to consumers regarding the sensitivity of regulators to their interests. This assumption is also consistent with commonly observed regulatory practice in which the firm's rate return is the focus of considerable political attention.[19] The firm's percentage rate of return serves as a focal point or performance indicator against which customers (or consumer

[18] A lower rate of return at a given price level is possible once we introduce a neoclassical production function and the substitution of capital inputs for non-capital inputs.

[19] See, for example, Caudill et al. (1993).

advocates) can compare to other well-known measures such as interest rates and other investment rates of return. In this sense, the rate of return complements customers' political support (or pressure) decision as a function of price (or consumer surplus) because the rate of return serves as an indicator to customers of how much additional consumer welfare may be possible (albeit, an imperfect indicator).[20]

Combining these assumptions, the regulator's political support function can be specified as

$$s = s\left(\pi, \omega, \gamma\right), \tag{1}$$

where π is the utility's profit level per unit of time, ω is an aggregate measure of consumers' welfare, and γ is the utility's rate of return on capital.[21] This objective function is assumed to be continuous and is characterized by $\partial s/\partial\pi > 0$, $\partial s/\partial\omega > 0$, and $\partial s/\partial\gamma < 0$. We retain the assumption of diminishing political returns from changes in any of these arguments: $\partial^2 s/\partial\pi^2 < 0$, $\partial^2 s/\partial\omega^2 < 0$, and $\partial^2 s/\partial\gamma^2 < 0$.[22] Consumer political support is a function of both consumer surplus (ω)[23] and rate of return (γ); however, Peltzman's first principle of regulation discussed above still holds in that the feasible minimum price and rate of return occurs at $\pi = 0$, marginal support from consumers diminishes in both these terms as economic profit approaches zero, and the marginal political support from the firm at $\pi = 0$ continues to dominate in our model just as it did in Peltzman's model.

Let f(L, K) be a continuous, quasiconcave production function that summarizes the firm's technology, where L is the physical level of the noncapital input (e.g., labor), and K is the physical level of the capital input, and $\partial f/\partial L$, $\partial f/\partial K > 0$. Market demand is given by the function $q = q(p)$, where p is the uniform price and $p = p(q)$ is the inverse demand function. Invoke a market clearing assumption, such that $q = q(p) = f(L, K)$. Furthermore, $p = p(f(L, K))$, and $\omega = \omega\,(p(f(L, K)))$.

[20] In the United States, the Fifth amendment of the constitution and case law, such as FPC v. Hope Natural Gas, 320 U.S. 591 (1944), also require just and reasonable returns to investors, which legally prevents a negative profit regulatory outcome and emphasizes a focus on the rate of return.

[21] Our inclusion of the rate of return in the regulator's political support function follows Evans and Garber (1988), who also provide a detailed justification on both theoretical and empirical grounds. Their inquiry, however, was limited to demonstrating an overcapitalization result. Note that we continue the convention first posited by Peltzman (1976) that the regulators' political support function is a positive function of economic profits even though it may be argued that shareholders really care about a rate of return (which is coincident with "profits" only if capital is fixed.) Similarly, an extension of the model proffered here might incorporate the potential (under information asymmetries) for consumers (and, hence, regulators) to "care" about accounting profits rather than the economic profits upon which we focus. This would arise if consumers were to focus on issues such as "How can those greedy guys earn so much money…?" rather than the economic profits. For a more general specification of the "benefits budget constraint" that regulators face, see Beard et al. (2003).

[22] As noted above, negative economic profit serves neither group in the long run because of bankruptcy and discontinuance of service. Thus we may have an implied discontinuity at $\pi = 0$ in terms of political support when profit falls below the normal profit level. In other words, price and rate of return are at their (long-run) feasible minimum when $\pi = 0$, and, therefore, consumer political support falls off when $\pi < 0$.

[23] On the assumption of quasilinear preferences for customers, the appropriate welfare measure, ω, is given by aggregate consumers' surplus: $\omega = \omega(p) = \int_p^\infty q(t)dt$ and thus , $d\omega/dp = -q$.

Profit may now be stated as $\pi = \pi(L, K) = f(L, K) \cdot p(f(L, K)) - rL - iK$, where r and i are the exogenously determined factor prices of the noncapital and capital inputs, respectively. The factor price of capital, i, is equal to its acquisition (equipment) cost multiplied by the financial capital cost. For simplicity and without loss of generality, assume that the acquisition cost of capital is equal to unity.[24] Profit is assumed to be strictly concave in the input space, (L, K).[25]

As is discussed above, a regulator with an objective as specified in (1) will never select a profit level that is zero (maximal) as long as marginal support for higher (lower) profits is positive. Therefore, a regulator optimum will involve profit that is strictly positive but less than its unregulated maximum.

Ignoring depreciation,[26] the firm's rate of return on capital, γ, is given by

$$\gamma = \gamma(L, K) = [f(L, K)p(f(L, K)) - rL] \div K.$$

The regulator's optimization problem can now be stated as:

$$\begin{aligned} &\text{MAX} \quad s[\pi(L, K), \omega(p(f(L, K))), \gamma] \\ &L, K, \gamma \\ &\text{s.t.} \quad \gamma = [f(L, K)p(f(L, K)) - rL] \div K \end{aligned} \tag{2}$$

The constraint in this problem can be restated as

$$g(L, K, \gamma) = f(L, K)p(f(L, K)) - rL - \gamma K = 0.$$

The solution to this problem yields the following propositions:

Proposition 1 *Neither a price cap constraint nor a rate-of-return constraint in isolation serves to realize the regulator's optimum.*

Proposition 2 *The regulator's optimum results in an inefficient capital bias but to a lesser degree than the capital bias that is associated with a firm that is constrained only in rate of return.*

Proofs of these propositions are found in Appendix 1. Figure 2 depicts the results within input space (L, K). The asterisks in the diagram denote the profit level (π^*), the output (price) level ($q^*(p^*)$), and rate-of-return contour (g^*) that correspond to the regulator's optimum (REG). Point AJ is the profit maximizing input combination when

24 See Averch and Johnson (1962, p. 1054) and Kennedy (1977) [p. 968].

25 Bailey (1973, p. 75) provides a proof that the rate of return constrained firm will not operate off the production frontier as long as $\partial f/\partial K > 0$, in contrast to Sherman (1992), who emphasizes that the firm may engage in "gold plating" to avoid operating in the inelastic region of demand. See Blank (1996), however, for a proof that the concavity restrictions on the profit and production functions remove the incentive to "gold plate".

26 Although depreciation is not considered here, depreciation rates are typically determined administratively by the regulator (sometimes in a separate case at a time between general rate cases) and, therefore, provides another way in which regulators can control price(s).

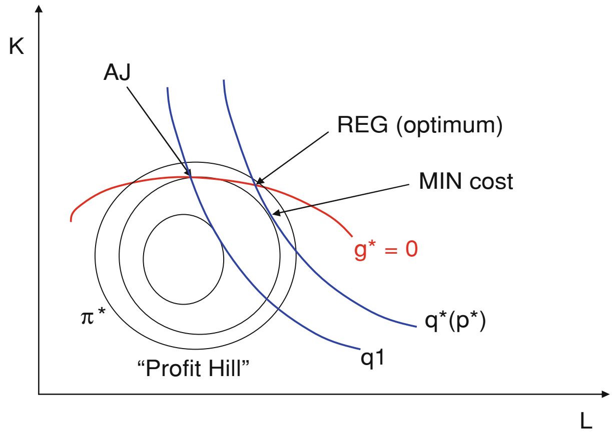

Fig. 2 Regulator's optimum in input space

the firm is only constrained by rate of return, γ^*, (i.e., point AJ is the Averch–Johnson result). At point AJ, the regulator can enhance political support on the margin by sacrificing profit (political support from the firm) in exchange for a lower price (higher output and political support from consumers). Point MIN is the least-cost input combination for the production of q^*. A firm only constrained in price, p^*, would obviously maximize profit at point MIN. At point MIN, however, the regulator can enhance political support on the margin by sacrificing profit (political support from the firm) in exchange for a lower rate of return (higher political support from consumers).[27] Neither ROR or PCAP regulation in isolation brings about the regulatory optimum. The regulator's objectives are served by the following set of constraints: $p \leq p^* (q^*)$ and $\gamma \leq \gamma^*$, and the firm will naturally select the input combination at point REG to maximize profit.

While Fig. 2 displays a unique regulatory optimum, the actual location of this equilibrium is more generally given by the interior of the triangular shaped region labeled "REG" in Fig. 3. The locus of the tangency points between the profit and rate of return contours is labeled "AJ locus" and is the set of all possible equilibria for the Averch–Johnson model when the allowed rate of return is varied.[28] The set of least-cost input combinations across different output levels is given by the line labeled "MIN locus". The boundary labeled "$\pi = g = 0$" depicts the zero-profit contour. At zero profit,

[27] Note that in the absence of political pressure from the customer interest group related to rate of return, clearly there would be an opportunity to enhance the welfare of the firm (without reducing consumer welfare) relative to the regulator's optimal choice of constraints through the use of pure "textbook" price cap regulation. With customer ignorance regarding the firm's technology, however, allowing the firm to move from REG to MIN in Fig. 1, as would occur under pure price cap regulation, will cause a decline in overall political support. This provides an explanation why pure price cap regulation is not commonly practiced. As will be considered in Sect. 4, a move away from REG toward MIN only has the potential of holding the regulator harmless in terms of political support if the regulator can transfer a portion of the rents gained by the firm to customers.

[28] Baumol and Klevorick (1970, pp. 171–172) present this locus in their analysis and formally establish its position relative to the least-cost locus.

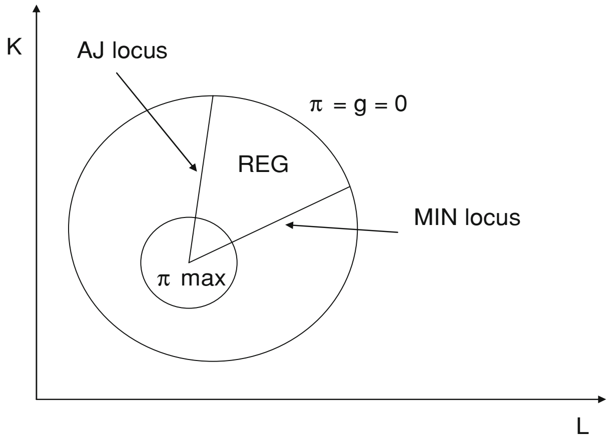

Fig. 3 Interior set of possible regulator optima

the rate of return contour (g = 0) coincides with the profit contour because $\gamma = \text{i}$. Invoking Peltzman's first principle of regulation discussed above, the regulator will neither select a point on the zero-profit contour nor the unregulated profit maximizing point ("πmax"). By Propositions 1 and 2, the regulator's optimum also cannot lie on either the AJ locus or the MIN locus. Therefore, the regulator's equilibrium is some interior point of set REG in Fig. 3.

Proposition 1 provides a new perspective on the extant literature that has allowed for the endogeneity of regulatory constraints. Specifically, while earlier research on surplus-maximizing regulators identified the potential for a rate-of return constraint to arise endogenously, and the positive political economy approach identified price as the regulator's constraint of choice, here we find that neither of these "pure" regulatory constraints alone provide a solution to the regulator's optimization problem. Rather a set of hybrid constraints are generally required to achieve the regulator's optimum.

This result also differs from Evans and Garber. In particular, Evans and Garber find that the regulatory equilibrium would involve the standard application of rate-of-return regulation with its consequent AJ inefficiencies and price setting.[29] In contrast to the results derived by Evans and Garber, however, our results indicate that the regulator desires a price constraint that is independently binding below the price that would occur under pure AJ-style rate-of-return regulation. Therefore, our model suggests that a form of hybrid regulation will serve the regulator's interests better than either pure price cap regulation or rate-of-return regulation.

Proposition 2 provides a new lens with which to view the efficiency consequences of regulatory constraints. For instance, as shown initially by AJ the imposition of a rate-of-return constraint on the firm leads to inefficiencies through overcapitalization. Besanko (1984) showed, however, that consumer surplus maximizing regulators

[29] A price constraint is established in Evans and Garber. That price, however, simply permits the firm to achieve its standard (AJ) rate-of-return with its attendant inefficiencies and thus has no independent regulatory content.

may, nonetheless, impose a rate-of-return constraint, with its attendant inefficiencies, to offset the disadvantages created by information asymmetries. In an entirely different modeling context, Evans and Garber (1988) too find that regulators are likely to impose a rate-of-return constraint and generate overcapitalization. Together, our Propositions 1 and 2, however, reveal that hybrid regulatory constraints are likely to emerge in equilibrium and that, as a consequence, the overcapitalization results to have emerged in the earlier research are likely to be attenuated. Importantly, though, while overcapitalization is less severe under hybrid regulation than under pure rate-of return regulation, it is not eliminated, as would be the case with the adoption of pure price caps.

4 Profit Sharing Plans

To this point, we have excluded the possibility of regulator-mandated transfers between the firm and consumers. Yet, profit sharing plans, under which the company returns a portion of its earned profit to customers (in the form of a refund or bill credit) when earnings rise above some threshold level, have been increasingly adopted in the past decade.[30] While economists have assessed the social welfare merits of these profit sharing plans relative to other forms of regulation,[31] the emergence of such regulator-mandated side payments between the regulated firm and consumers has yet to be formally demonstrated.[32] Here, then, we formally explore whether profit sharing may arise endogenously as a means to enhance political support for the regulator within the context of the model presented in Sect. 3.

Returning to Fig. 2, it is clear that a movement from REG to MIN will enhance profit (and rate of return) while holding consumer welfare in terms of price constant. Based on the earlier analysis, this will cause a decline in the regulator's political support, giving an explanation for why pure price cap regulation is not commonly practiced.[33] Consider, though, the possibility of sharing the profit gained through more efficient

[30] Abel and Clements (1998) observe that "…it is common to find states employing a price-cap plan that also has an earnings-sharing component to the regulatory constraint…" (p.13).

[31] See, e.g., Sappington and Sibley (1992), Weisman (1993), Sappington and Weisman (1996), and Lyon (1996).

[32] Previous authors have informally alluded, though, to the wellspring of profit sharing. For instance, Sappington and Weisman (1996) note that "…profit sharing schemes are popular even though it is well known that profit sharing can reduce incentives for cost-reducing effort. The popularity of profit-sharing schemes stems from their ability to limit the profits that regulated firms earn." (p.234, fn. 8). Similarly, Schmidt (2000) notes that: "If the public…sees utilities earning above normal returns, political pressure may be brought to bear. The answer is earnings sharing. Give the regulator something to offer up to their constituents…" (p. 104). And Sappington (2002, p. 207) notes that regulators may be averse to high earning that are possible under pure price caps because "constituents may view high earnings as a sign that the regulator favoured the firm unduly when designing the price cap regime."

[33] Sappington and Weisman (1996) demonstrate that some revenue sharing is Pareto optimal relative to pure profit sharing. Within the context of our model, profit sharing dominates revenue sharing in terms of political support for the regulator because revenue sharing would allow the firm to move to cost minimizing output without increasing revenue (hence no sharing), increase profit, and the rate of return would rise. Such a result is effectively the same as pure price cap regulation within the context of our model and is, therefore, dominated by both our hybrid result and profit sharing.

production. Specifically, consider the impact of profit sharing on the regulator's political support relative to REG. To determine whether profit sharing is optimal for the regulator, we relax the rate of return constraint but maintain the price constraint at REG with profit sharing. Let α, where $0 < \alpha < 1$, represent the fraction of profit above the REG profit level that will be transferred to the customers. With a relaxed rate-of-return constraint, the firm clearly has an incentive to substitute L for K, thereby reducing cost while holding revenue constant; that is, the increase in L cost is more than offset by the decrease in K cost. Let M represent the maximum value function for the regulator's problem (2): $\mathrm{M} = \mathrm{s}[\pi(\mathrm{L}^*, \mathrm{K}^*), \omega(\mathrm{p}(\mathrm{f}(\mathrm{L}^*, \mathrm{K}^*))), \gamma^*]$. Implementation of profit sharing and a price cap with M as the starting point implies the following for profit, consumer welfare, and the constraint function, $\mathrm{g}(\mathrm{L}, \mathrm{K}, \gamma)$, respectively:

$$\pi = \pi(\mathrm{L}^*, \mathrm{K}^*) + (1 - \alpha)[\pi(\mathrm{L}, \mathrm{K}) - \pi(\mathrm{L}^*, \mathrm{K}^*)]; \tag{3}$$

$$\omega = \omega(\mathrm{p}(\mathrm{f}(\mathrm{L}^*, \mathrm{K}^*))) + \alpha[\pi(\mathrm{L}, \mathrm{K}) - \pi(\mathrm{L}^*, \mathrm{K}^*)]; \tag{4}$$

$$\mathrm{g} = \mathrm{g}(\mathrm{L}, \mathrm{K}, \gamma) - \alpha[\pi(\mathrm{L}, \mathrm{K}) - \pi(\mathrm{L}^*, \mathrm{K}^*)].^{34} \tag{5}$$

The terms without asterisks in (3), (4), and (5) are those added with the implementation of profit sharing. Given this profit sharing regime, we have:

Proposition 3 *A price constraint combined with profit sharing enhances the regulator's political support relative to the solution of the regulator's problem* (2)*, M, as long as the fraction shared with customers, α, meets the following condition*:
$\alpha < \left(\frac{(\partial s/\partial \pi)i - \lambda\gamma}{(\partial s/\partial \pi)i - \lambda i}\right)$, *where the ratio is less than one* (*but greater than zero*) *because* $\gamma > i$. *The proof of Proposition* 3 *is provided in Appendix* 2.

On the margin, therefore, the regulator can enhance political support by requiring some profit sharing, and the price cap/profit sharing regime will include a fraction of additional profit retained by the firm $(1 - \alpha)$ greater than some threshold percentage (i.e., one minus the ratio stated in Proposition 3). The greater the difference between the regulated rate of return, γ, and actual cost of capital, i, the greater the share of additional profit that will be retained by the firm under the profit sharing scheme. That is, a higher γ in the solution to the regulator's adoption of hybrid regulation without profit sharing, M, suggests that customers are relatively less sensitive to the rate of return level and the amount of additional profit retained by the firm can be higher. The movement to profit sharing while holding price constant enhances political support for the regulator through higher profit (support from the firm), and the wealth transfer to customers is valued more by customers on the margin than the realized increase in the rate of return that will result. Our results may explain why many regulatory agencies have implemented price caps in the context of a profit sharing plan. Note also that a price cap with profit sharing also improves production efficiency relative to REG in Fig. 2.

[34] Note that unlike the regulator's problem (2), the rate of return will not be independently constrained under this regime.

Proposition 3 does not, however, imply that the regulator will allow the firm to move entirely to MIN in Fig. 2. Indeed, regulatory agencies often cap the profit level by requiring a 100% transfer to customers for earnings above some threshold, thereby removing the incentive for the firm to adopt the cost-minimizing combination of L and K. Accordingly, we now consider the production efficiency implications of Proposition 3 in input space. Once again, as a starting point, we begin with the maximum value function, M, and implement profit sharing with the price cap implied by M. The regulator's problem is

$$\begin{aligned}&\text{MAX} \quad \text{s}[\pi, \omega, \gamma] \\ &\text{L, K} \\ &\text{s.t.} \quad \text{g} = 0\end{aligned} \tag{6}$$

where the variable terms in π, ω, and g from equations (3), (4), and (5), above, are as follows:

$$\begin{aligned}\Delta\pi &= (1-\alpha)\pi(\text{L, K}); \\ \Delta\omega &= \alpha\pi(\text{L, K}); \text{ and}\end{aligned}$$

$\Delta \text{g} = \text{g}(\text{L, K}, \gamma) - \alpha\pi(\text{L, K})$, where the notation Δ simply indicates the change function of the dependent variable relative to the maximum value function, M. Problem (6) gives us:

Proposition 4 *The regulator continues to desire some degree of overcapitalization under the price cap/profit sharing regime. The proof is provided in Appendix* 3.

The regulator's optimum with profit sharing lies somewhere between REG and MIN along the isoquant q* in Fig. 2. Inefficient production of q* through overcapitalization continues to serve the regulator's interest. Of course, the firm under the profit sharing scheme described thus far will maximize profit by selecting the cost-minimizing combination of L and K: point MIN. The regulator, therefore, must modify the profit sharing plan to prevent the firm from moving to MIN, which would result in a rate of return that is unacceptable to the regulator. The solution that naturally emerges is to limit the earnings retained by the firm. By simple logic we have:

Corollary 1 *The solution to the regulator's problem* (6) *can be invoked by adding to the profit sharing/price cap regime an earnings level threshold, beyond which* 100% *of additional profit must be transferred to consumers.*

With inclusion of a binding profit level threshold in the regime, the firm has no incentive to adopt the cost-minimizing input combination. Figure 4 depicts a typical profit sharing regime as adopted by regulators.[35] The design is consistent with Corollary 1 as the upper-bound constraint on earnings serves regulator's self-interested objective. Segment A in Fig. 4 corresponds to the earning level implied by M prior

[35] See Sappington (2002, p. 229).

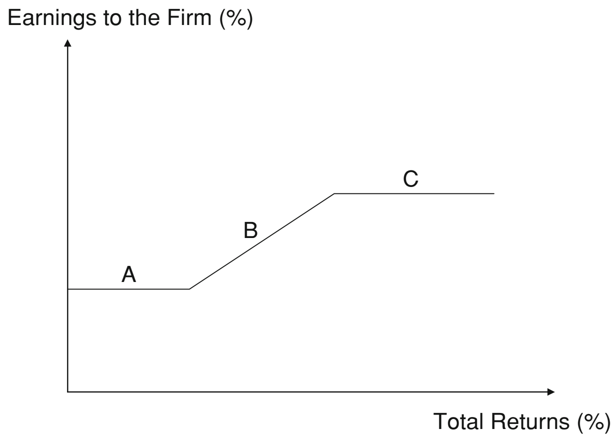

Fig. 4 Profit sharing

to consideration and implementation of profit sharing. Segment B corresponds to the sharing of profits between the firm and consumers over some range. Segment C in the diagram is that level where 100% of additional earnings go to consumers and is the value in the solution to the regulator's problem with profit sharing. So why is it that regulators limit earnings that could be retained by the firm when the additional profit for sharing stems from an increased incentive for the firm to minimize costs? The answer appears to lie in the political pressure from customers as the firm's realized rate of return rises with reduced production inefficiency.

In summary, we have Proposition 3, in which a price cap/profit sharing regime arises simply by adding wealth (profit) transfers to customers, and we have Proposition 4 and Corollary 1, suggesting a regulatory regime in which some degree of production inefficiency continues to characterize the regulator's optimum and the firm's share of additional profit is capped, arises because of the customers' continued pressure against the rising realized rate of return. In our model, therefore, segment C arises endogenously as a vehicle for maximizing the regulator's political support.

5 Discussion

Our results provide insights into the adoption of simple hybrid (without side payments) regulation, more complex hybrid regulatory regimes that involve side payments (profit sharing) and finally hybrid regulation with caps on profit sharing (sliding scale regulation). While these results stem from a positive model of regulator behavior, some interesting parallels arise with the normative literature on these alternative regulatory designs. For example, Sappington (1983) explores an optimal strategy for an expected consumer surplus maximizing regulator that faces a regulated multiproduct firm with unknown technological capabilities. He demonstrates that the optimal policy in such a setting will induce the firm to incur costs in excess of the minimum feasible costs. This yields a parallel to our Propositions 2 and 4, which indicate that cost excesses, here in the form of biased input choices, will similarly arise in the context of a positive model of regulator performance.

Similarly, Lewis and Sappington (1989) specify conditions under which the optimal (i.e., consumer surplus less auditing cost) regulatory policy is to afford the firm a choice between a profit sharing regime and a price cap regime. Our results meld this "either-or" option into the potential for hybrids between these regulatory alternatives. Moreover, akin to our results, their profit sharing mechanism leads to distortions in welfare as a result of reduced incentives for cost minimizing behavior.

Sappington and Sibley (1992) demonstrate that a small increase in sharing relative to no sharing under two variants of price cap regulation enhances social welfare (i.e., the sum of consumer plus producer surplus) when the firm can make observable cost-reducing investments. While their results point, from a normative perspective, toward the potential merits of adopting profit sharing regimes, our results (viz., Proposition 3 and Corollary 1) indicate that such profit sharing regimes are indeed likely to arise and will be designed with complete sharing for earnings above certain levels.

Finally, Lyon (1995, 1996) also analyzes profit sharing; he utilizes a model in which cost-reducing effort is costly and not directly observable by the regulator. The specific form of profit-sharing is one with a "deadband" range of earnings within which the firm is the residual claimant of increases or decreases in profit. The deadband has upper and lower bounds in terms of earnings levels that are determined (though exogenously) by interest group strengths. Lyon's focus, however, is not on the existence or determinants of these bounds, but rather on their welfare implications. In Lyon (1995), he demonstrates that a combination of regulatory constraints (viz. deadband with profit sharing) can induce more efficient choices by regulated firms regarding technologies. In Lyon (1996), he assesses whether inclusion of a profit (loss) sharing parameter enhances social welfare. He finds that, relative to pure price cap regulation, some amount of profit sharing always improves expected welfare. Again, an interesting parallel arises as our results suggest, from a positive perspective, that not only might these efficiency gains from hybrid regulation be possible but that they may well arise in practice.

6 Conclusion and Directions for Future Research

Models of public utility regulation are often framed, alternatively, as rate-of-return or price-cap regulation. In practice, however, regulators have increasingly adopted a variety of hybrid regulatory constraints that embody elements of both rate-of-return and price cap regulation. In this paper, we draw upon elements of both the positive economic theory of regulation and standard efficiency-based economic analysis of regulation to develop a model that endogenously yields hybrid regulatory constraints as a regulatory optimum. Furthermore, the paper endogenously demonstrates the role of profit sharing regulation as a vehicle for advancing regulator welfare. These results provide a plausible basis for the modern evolution of regulatory constraints. Also, whether adopted in simple or more complex forms, hybrid regulation is seen to retain elements of cost inefficiencies identified in rate-of-return regulation.

In this context, it is important to recognize that the variation in hybrid regulatory mechanisms seen in practice is arguably more one of degree, not one of substance. Future theoretical explanations for the observed degree of variation in hybrid regulatory schemes, however, may prove to be of great interest, and we hope that our theoretical explanation for the general characteristics of hybrid regulation will stimulate such research.

As with any conceptual representation, our analysis is necessarily constrained by the simplifications that we have adopted in developing the model. In this spirit, we point out that throughout our analysis we have precluded the possibility that regulators directly control input levels. In practice, regulators may limit expenses and capital investments or proposed capital projects.[36] In so doing, they may, albeit imperfectly, affect input levels. Accordingly, a reasonable model extension may be to introduce regulators that can pursue their objectives via more direct control over firms' input choices.

Similarly, the extant model avoids the complications brought about by demand and/or cost shocks. These are, however, an important reality in essentially all regulated markets, so their inclusion in the model may enrich the results that we have been able to generate. Additionally, the extension of the model to a multi-period setting may yield considerable fruit. Further, a multi-tiered setting in which regulators themselves are held (at least partially) accountable to a legislative body may provide additional insights. It may also be possible to enrich the model by palatable extensions of the regulator support function. The regulator support function may be extended to include, for example the quality of the regulated firm's offerings.

Finally, in recent years, the importance of regulatory, political and legal institutions in shaping economic outcomes has increasingly been demonstrated. Thus, our inquiry naturally raises a number of questions regarding how the nature of these institutions may act upon the results derived here.[37]

Appendix 1

Proof of Propositions 1 and 2 The necessary, first order conditions for the regulator's political support problem in (2) are

$$\frac{\partial s}{\partial \pi}\frac{\partial \pi}{\partial L} + \frac{\partial s}{\partial \omega}\frac{d\omega}{dp}\frac{dp}{df}\frac{\partial f}{\partial L} - \lambda\frac{\partial g}{\partial L} = 0 \tag{A}$$

$$\frac{\partial s}{\partial \pi}\frac{\partial \pi}{\partial K} + \frac{\partial s}{\partial \omega}\frac{d\omega}{dp}\frac{dp}{df}\frac{\partial f}{\partial K} - \lambda\frac{\partial g}{\partial K} = 0 \tag{B}$$

$$\frac{\partial s}{\partial \gamma} - \lambda\frac{\partial g}{\partial \gamma} = 0 \tag{C}$$

[36] Note, though, that this control is often exerted ex post, and often is unrelated to ex ante determinations of efficient input combinations. See, e.g., the discussions in Lyon (1991) and Lyon and Mayo (2005).

[37] An interesting step in this direction is provided by Donald and Sappington (1995) who explore the empirical determinants of regulatory regime choice for US telecommunications firms.

$$g(L, K, \gamma) = 0, \tag{D}$$

where λ is the Lagrangean multiplier and $0 < \lambda < \partial s/\partial\pi$ in equilibrium. The positive value for λ is established by condition (C) and $\partial s/\partial\gamma < 0$, and $\partial g/\partial\gamma < 0$. The second term in (A) is clearly positive, and $\partial\pi/\partial L = \partial g/\partial L < 0$; therefore, condition (A) is satisfied if and only if $\lambda < \partial s/\partial\pi$.

Note that:

$$\partial\pi/\partial L = \partial g/\partial L = f(L, K)\, dp/df\, \partial f/\partial L + p(f(L, K))\, \partial f/\partial L - r;$$
$$\partial\pi/\partial K = f(L, K)\, dp/df\, \partial f/\partial K + p(f(L, K))\, \partial f/\partial K - i; \text{ and}$$
$$\partial g/\partial K = f(L, K)\, dp/df\, \partial f/\partial K + p(f(L, K))\, \partial f/\partial K - \gamma.$$

Making the appropriate substitutions and rearranging terms, condition (A) reduces to:

$$\frac{r}{\partial f/\partial L} = f(L, K)\frac{dp}{df} + p(f(L, K)) + \frac{(\partial s/\partial\omega)(d\omega/dp)(dp/df)}{(\partial s/\partial\pi) - \lambda} \tag{E}$$

Similarly, condition (B) reduces to:

$$\frac{i}{\partial f/\partial K} = f(L, K)\frac{dp}{df} + p(f(L, K)) + \frac{(\partial s/\partial\omega)(d\omega/dp)(dp/df)}{(\partial s/\partial\pi) - \lambda} + \frac{\lambda(\gamma - i)}{(\partial f/\partial K)[(\partial s/\partial\pi) - \lambda]} \tag{F}$$

Combining conditions (E) and (F) results in

$$\left(\frac{i}{\partial f/\partial K}\right) - \left(\frac{r}{\partial f/\partial L}\right) = \frac{\lambda(\gamma - i)}{(\partial f/\partial K)[(\partial s/\partial\pi) - \lambda]} \tag{G}$$

The difference in (G) is strictly positive because, as demonstrated above, $0 < \lambda < \partial s/\partial\pi$, and profit is strictly positive[38], implying that $\gamma > i$. Therefore, in equilibrium:

$$\left(\frac{i}{\partial f/\partial K}\right) > \left(\frac{r}{\partial f/\partial L}\right). \tag{H}$$

From neoclassical theory, condition (H) implies an inefficient capital bias relative to the least cost input combination, which requires $i/(\partial f/\partial K) = r/(\partial f/\partial L)$.[39] It follows that a simple price constraint, which will encourage least cost production by the firm, will not achieve the regulator's optimum. □

Our overcapitalization result differs from that derived using early models of the rate-of-return constrained firm,[40] however, because the capital bias is now less severe.

38 This is demonstrated in the text as attributed to Peltzman (1976).

39 See Baumol and Klevorick (1970, pp. 165-167).

40 Averch and Johnson (1962) and Wellisz (1963).

This can be proven by contradiction. Let γ^* denote the equilibrium rate of return level derived in solving the regulator's problem (2). If the regulator only constrains the firm in rate of return at level γ^*, the firm is regulated in the spirit of Averch and Johnson (1962), hereafter "AJ firm". The problem facing the AJ firm can be stated as

$$\text{MAX} \quad \pi(\text{L}, \text{K}) = \text{f}(\text{L}, \text{K}) \cdot \text{p}(\text{f}(\text{L}, \text{K})) - \text{rL} - \text{iK}$$
$$\text{s.t. } \text{g}(\text{L}, \text{K}, \gamma^*) = \text{f}(\text{L}, \text{K})\text{p}(\text{f}(\text{L}, \text{K})) - \text{rL} - \gamma^*\text{K} = 0.$$

One of the necessary conditions for constrained profit-maximization is

$$\frac{\partial\pi}{\partial \text{L}} - \lambda\frac{\partial \text{g}}{\partial \text{L}} = 0 \tag{I}$$

The Lagrangean multiplier for this problem is bounded as $0 < \lambda < 1$ (the constraint is binding and $\gamma^* > \text{i}$). Once again, note that $\partial\pi/\partial\text{L} = \partial\text{g}/\partial\text{L}$, everywhere. The firm's optimality condition (I) requires $\partial\pi/\partial\text{L} = \partial\text{g}/\partial\text{L} = 0$. We now return to the regulator's political maximization problem (2) and the following first order condition (A):

$$\frac{\partial s}{\partial\pi}\frac{\partial\pi}{\partial \text{L}} + \frac{\partial s}{\partial\omega}\frac{d\omega}{d\text{p}}\frac{d\text{p}}{d\text{f}}\frac{\partial \text{f}}{\partial \text{L}} - \lambda\frac{\partial \text{g}}{\partial \text{L}} = 0. \tag{A}$$

Substituting $\partial\pi/\partial\text{L}, \partial\text{g}/\partial\text{L} = 0$ as required for an AJ firm, the left hand side of equation (A) reduces to $\frac{\partial s}{\partial\omega}\frac{d\omega}{d\text{p}}\frac{d\text{p}}{df}\frac{\partial f}{\partial L}$. Because this expression is always positive, we have a contradiction. The conditions required for the regulator's optimum are not satisfied by the solution to the AJ firm's problem. The positive value on the left hand side of (A) when evaluated at the AJ firm solution implies that the regulator desires greater employment of L (less K) along the rate of return locus associated with γ^* (that is, the regulator wants lower price, greater output). Holding the rate of return constant, greater output achieved with more L implies a reduction in K relative to the AJ firm solution.[41] It follows that a rate-of-return constraint in isolation, which will encourage the firm to select the AJ result, will not bring about the regulator's optimum. □

Appendix 2

Proof of Proposition 3 The firm can enhance profit by substituting L for K, implying a net decrease in cost iK (net of rL). Output and price remain fixed at f(L*, K*) and p(f(L*, K*)), respectively. Substituting Eqs. (3), (4), and (5) into the maximum value function, M, and the constraint function, g, we can assess the impact of a change in K on M, the regulator's political support. Because the capital cost decrease more than offsets the L cost increase, we can treat K as the only variable.

[41] As demonstrated by Zajac (1970) and Baumol and Klevorick (1970), the level of capital (K) at the AJ firm solution is the maximum capital level along the constraint boundary defined by $\text{g}(\text{L}, \text{K}, \gamma^*) = 0$. Thus any point along this boundary other than the AJ firm desired point involves less K.

$$\begin{aligned} dM/dK &= (1-\alpha)(\partial s/\partial\pi)(\partial\pi/\partial K) + \alpha(\partial s/\partial\omega)(\partial\omega/\partial\pi)(\partial\pi/\partial K) \\ &\quad -\lambda\left[(\partial g/\partial K) - \alpha\,(\partial\pi/\partial K)\right] \\ &= (1-\alpha)\,(\partial s/\partial\pi)\,(-i) + \alpha\,(\partial s/\partial\omega)\,(-i) - \lambda\,(-\gamma+\alpha i) \\ &= \left[-\,(\partial s/\partial\pi)\,i + \lambda\gamma\right] + \alpha\,[(\partial s/\partial\pi)\,i - \lambda i] + \alpha\,(\partial s/\partial\omega)\,(-i). \end{aligned} \tag{A}$$

The regulator will pursue a price cap/profit sharing regime if and only if this expression is negative (i.e., a decrease in K along the isoquant brings about a marginal increase in political support, M). The last term in this expression is clearly negative, but is also irrelevant because a price cap/profit sharing regime will not affect ω (price remains unchanged). We know that the first bracketed term is negative because from equation (B) in Appendix 1, we have: $(\partial s/\partial\pi)\,(\partial\pi/\partial K) < \lambda\,(\partial g/\partial K)$, or $(\partial s/\partial\pi)\,i > \lambda\gamma$. For the entire expression (A) to be negative, therefore, we have the following condition:

$\alpha < \left(\frac{(\partial s/\partial\pi)i-\lambda\gamma}{(\partial s/\partial\pi)i-\lambda i}\right)$, where the ratio is less than one (but greater than zero) because $\gamma > i$. Therefore, a price cap/profit sharing regime will be adopted by the regulator but the percentage shared with the customers, α, must be below the stated threshold. The net decrease in capital costs under profit sharing will increase political support, M. □

Appendix 3

Proof of Proposition 4 and related Corollary Two of the first order conditions for problem (6) are:

$$\begin{aligned} &(1-\alpha)\partial s/\partial\pi\left[f(L,K)dp/df\;\partial f/\partial L + p\,(f(L,K))\;\partial f/\partial L - r\right] \\ &+\alpha\partial s/\partial\omega\left[f(L,K)dp/df\,\partial f/\partial L + p\,(f(L,K))\;\partial f/\partial L - r\right] + \alpha\lambda\left[f(L,K)dp/df\;\partial f/\partial L\right. \\ &\left.+\,p\,(f(L,K))\;\partial f/\partial L - r\right] - \lambda\left[f\,(L,K)\;dp/df\;\partial f/\partial L + p\,(f(L,K))\;\partial f/\partial L - r\right] \\ &= 0;\text{ and} \end{aligned} \tag{A}$$

$$\begin{aligned} &(1-\alpha)\partial s/\partial\pi\left[f(L,K)dp/df\;\partial f/\partial K + p\,(f(L,K))\;\partial f/\partial K - i\right] \\ &+\alpha\partial s/\partial\omega\left[f(L,K)dp/df\;\partial f/\partial K + p\,(f(L,K))\;\partial f/\partial K - i\right] + \alpha\lambda\left[f(L,K)dp/df\;\partial f/\partial K\right. \\ &\left.+p\,(f(L,K))\;\partial f/\partial K - i\right] - \lambda\left[f(L,K)dp/df\;\partial f/\partial K + p\,(f(L,K))\;\partial f/\partial K - \gamma\right] = 0. \end{aligned} \tag{B}$$

Condition (A) may be stated as:

$$\begin{aligned} \frac{r}{\partial f/\partial L} &= f\bullet\frac{dp}{df} + p + \frac{\lambda\, r}{(\partial f/\partial L)[(1-\alpha)(\partial s/\partial\pi) + \alpha(\partial s/\partial\omega) + \alpha\lambda]} \\ &\quad - \frac{\lambda[f\bullet(dp/df) + p]}{(1-\alpha)(\partial s/\pi) + \alpha(\partial s/\partial\omega) + \alpha\lambda} \end{aligned} \tag{C}$$

Similarly, condition (B) reduces to:

$$\frac{\mathrm{i}}{\partial \mathrm{f}/\partial \mathrm{K}} = \mathrm{f} \bullet d\frac{\mathrm{p}}{d\mathrm{f}} + \mathrm{p} + \frac{\lambda\gamma}{(\partial \mathrm{f}/\partial \mathrm{K})[(1-\alpha)(\partial \mathrm{s}/\partial\pi) + \alpha(\partial \mathrm{s}/\partial\omega) + \alpha\lambda]} - \frac{\lambda[\mathrm{f}\bullet(d\mathrm{p}/d\mathrm{f}) + \mathrm{p}]}{(1-\alpha)(\partial \mathrm{s}/\pi) + \alpha(\partial \mathrm{s}/\partial\omega) + \alpha\lambda} \tag{D}$$

Combining conditions (C) and (D) results in

$$\frac{\mathrm{i}}{\partial \mathrm{f}/\partial \mathrm{K}} - \frac{\mathrm{r}}{\partial \mathrm{f}/\partial \mathrm{L}} = \left[\frac{\gamma}{\partial \mathrm{f}/\partial \mathrm{K}} - \frac{\mathrm{r}}{\partial \mathrm{f}/\partial \mathrm{L}}\right] \bullet \frac{\lambda}{(1-\alpha)(\partial \mathrm{s}/\partial\pi) + \alpha(\partial \mathrm{s}/\partial\omega) + \alpha\lambda}. \tag{E}$$

From (E), we know that $\left(\frac{\mathrm{i}}{\partial \mathrm{f}/\partial \mathrm{K}}\right) > \left(\frac{\mathrm{r}}{\partial \mathrm{f}/\partial \mathrm{L}}\right)$ insofar as $\left(\frac{\gamma}{\partial \mathrm{f}/\partial \mathrm{K}}\right) > \left(\frac{\mathrm{r}}{\partial \mathrm{f}/\partial L}\right)$. We know this condition holds at REG as demonstrated in the proof of Proposition 2. At the cost-minimizing point, MIN, we have $\left(\frac{\mathrm{i}}{\partial \mathrm{f}/\partial \mathrm{K}}\right) = \left(\frac{\mathrm{r}}{\partial \mathrm{f}/\partial \mathrm{L}}\right)$ and $\gamma > \mathrm{i}$ (note that with profit sharing, the rate of return, γ, increases as the firm moves from REG toward MIN in Fig. 1). Therefore, in the solution to problem (6), it follows that $\left(\frac{\mathrm{i}}{\partial \mathrm{f}/\partial \mathrm{K}}\right) > \left(\frac{\mathrm{r}}{\partial \mathrm{f}/\partial \mathrm{L}}\right)$ because $\left(\frac{\gamma}{\partial \mathrm{f}/\partial \mathrm{K}}\right) > \left(\frac{\mathrm{r}}{\partial \mathrm{f}/\partial \mathrm{L}}\right)$at all points between REG and MIN inclusive of point MIN, where $\gamma > \mathrm{i}$; therefore, at MIN we have a contradiction with condition (E). □

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