

REVIEW OF EMPIRICAL INVESTIGATIONS  
OF THE A-J HYPOTHESIS

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Executive Summary

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In 1962 Averch and Johnson developed a microeconomic model of constrained profit-maximization, where the (only) constraint is that "profits" may not exceed a certain allowed rate of return prescribed by a regulatory commission. This fairly straight-forward model leads to several hypotheses about the behavior of profit-maximizing firms subject to a rate of return constraint. The most interesting hypothesis, both economically and politically, is that regulated firms will over-employ capital in their production process.

The Averch-Johnson hypothesis follows directly from the regulatory mechanism employed in their model and the assumption of profit maximizing behavior by the firm. The A-J analysis assumes perfect certainty and implies that regulation is continuous. Also, regulators are taken to be so inept or single-minded that they allow a rate base greater than the cost-minimizing rate base. Based on these assumptions the A-J model is technically correct.

However, the A-J paradigm has been challenged by Paul Joskow on the grounds that regulatory authorities do not operate in the simplistic, single-minded manner that A-J assumes, and on the grounds that firms are not strict single-period profit-maximizers. Joskow views the regulators as seeking to avoid criticism and public dissatisfaction, while

the firm is viewed as seeking long-run profit maximization in a loose sense. Hence, the regulators allow firms to keep any profits above or below the "allowed" level and intervene only when the firm asks for a nominal price increase. Since Joskow's model of regulation allows firms to keep any profits they can earn in excess of the allowed rate, firms will generally seek to minimize costs. Only in periods when costs are rising and when firms are constantly requesting price increases does the A-J model appear to have operational content.

There have been several attempts to empirically test the A-J hypothesis. Cohen summarizes the methodology and results of nine empirical studies from 1970-1978. Of these studies, about half report results confirming the existence of an A-J capital bias, while the other half, finding no such bias, do not support the hypothesis. In fact, the most sophisticated and appealing model, that of Barron and Taggart, yields results that even suggest a reverse A-J effect. The results of most of these studies however, are highly questionable due to some very serious estimation problems. This seems to be particularly true of those supporting the A-J hypothesis.

It would be satisfying to make a strong statement about the existence or non-existence of the capital bias behavior that the A-J model predicts. That is not possible given the present state of the art. While the studies that support its existence suffer from econometric estimation problems, the evidence does not completely rule out the possibility that

the bias exists. What we can say is that even if an A-J tendency to over or under-employ capital exists, so many dynamic changes and uncertainties plague both the firm's decision makers and our modeling attempts that the A-J tendency does not unambiguously reveal itself.

## Introduction

In 1962 Averch and Johnson [1] developed a micro-economic model of constrained profit-maximization, where the (only) constraint is that 'profits' may not exceed a certain allowed rate of return prescribed by a regulatory commission. This fairly straight-forward model leads to several hypotheses about the behavior of profit-maximizing firms subject to a rate-of-return constraint. The most interesting hypothesis, both economically and politically, is that regulated firms will over-employ capital in their production process. In this paper, several of the empirical investigations into this hypothesis will be discussed.<sup>1</sup> To expedite the review of these empirical studies, the paper begins by briefly developing the A-J hypothesis. In the second section the counter-arguments provided by Joskow [13] and others are discussed. In section three, nine empirical studies of the A-J hypothesis are reviewed. The empirical results are inconclusive, reflecting the limitations of the A-J hypothesis.

### I. The Averch-Johnson Model

In their now-classic article, Averch and Johnson construct the constrained maximization problem of a monopolistic firm

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<sup>1</sup>Although the A-J article deals with all regulated firms, all of the empirical work reviewed here was conducted on electric utilities. In fact, telephone utilities' behavior was the concern of the applied portion of their paper. For a recent study of firm behavior in the natural gas transmission industry, see Callen [24].

producing a single output with two inputs, capital (K) and labor (L). The firm operates under the single-minded control of a regulatory authority which sets an allowed rate of return,  $s$ . The value of  $s$  is assumed to exceed  $P_K$ , the firm's cost of capital, and to be below  $r_m$ , the profit-maximizing rate of return. For convenience, depreciation is assumed to be zero. Let the profit function be:  $\pi = PZ - P_K K - P_L L$  where

$\pi$  = profit

$Z = g(K, L)$  is output and  $g(K, L)$  is the production function

and  $\frac{\partial Z}{\partial K} > 0$ ,  $\frac{\partial Z}{\partial L} > 0$ ,  $g(K, 0) = g(0, L) = 0$

$P = f(Z)$  is the inverse demand function

$K, L$  defined as units of inputs such that  $P_K K$  = payments to capital  $P_L L$  = payments to labor.

The constraint may be written as:  $(PZ - P_L L) \div K \leq S$ .

The appropriate Langrangran expression is<sup>2</sup>:

$$(1) \quad L(K, L, \lambda) = PZ - P_L L - P_K K - \lambda [PZ - SK - P_L L] \text{ and}$$

the first order conditions are:

$$(2) \quad MRP_K (1 - \lambda) - P_K + \lambda S = 0$$

$$(3) \quad MRP_L (1 - \lambda) - P_L + \lambda P_L = 0$$

$$(4) \quad PZ - SK - P_L L = 0$$

where  $MRP_K \equiv$  marginal revenue product of capital =

$\frac{\partial (PZ)}{\partial Z} \cdot \frac{\partial Z}{\partial K}$  and  $MRP_L$  defined similarly as the marginal

revenue product of labor.

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<sup>2</sup>A-J treat the constraint as an equality (as do later theorists) making it unnecessary to use the Kuhn-Tucker conditions to solve for a maximum.

Under the A-J assumption that  $S > PK$  it follows from (2) that  $\lambda \neq 1$ . Then, dividing (2) by (3), rearrange to obtain:

$$(5) \frac{MPK}{MP_L} = \frac{PK}{PL} - \lambda(S - PK)/(1 - \lambda)P_L \text{ where}$$

$$MP_K \equiv \text{marginal product of capital} = \frac{\partial Z}{\partial K}, \text{ and similarly}$$

$$\text{for } MP_L.$$

The cost-minimizing solution for an unconstrained firm would be: (6)  $\frac{MPK}{MPL} = \frac{PK}{PL}$ . Hence the constrained firm is not minimizing costs since (5) only reduces to (6) for  $\lambda = 0$ . But by assumption,  $\lambda \neq 0$  because  $s < r_m$ . To proceed from this result to the A-J hypothesis that regulated firms employ capital beyond the cost-minimizing point, it must be shown that the left-hand side of (5) is less than  $\frac{PK}{PL}$ .<sup>3</sup> This requires that  $\lambda$  satisfy:  $0 < \lambda < 1$ . That  $\lambda$  is greater than zero follows from the Kuhn-Tucker conditions on (1). The A-J assumptions that  $S < r_m$  implies  $\lambda \neq 0$ . The condition  $\lambda < 1$  can be shown to hold by developing the appropriate second order conditions on (1), given  $Z = g(K,L)$  is concave.<sup>4</sup>

The constrained firm utilizes inputs in the manner prescribed by (5) with  $0 < \lambda < 1$ ; given a diminishing marginal rate of technical substitution, the regulated firm produces its output with a capital-labor ratio in excess of that which an unconstrained (cost-minimizing) profit-maximizing firm would use to produce that output. This is the A-J hypothesis.

<sup>3</sup>Given that  $Z = g(K,L)$  is a well-known neo-classical production function,  $\frac{MPK}{MPL} < \frac{PK}{PL}$  implies over-capitalization, the A-J hypothesis.

<sup>4</sup>See Baumol and Klevorick [6], pages 166-167.

Several interpretations of the A-J hypothesis suggest that the regulated firm will produce with a higher capital-labor ratio than an unregulated firm. This is generally incorrect, as Baumol and Klevorick point out.<sup>5</sup> The correct statement is "The regulated firm will produce with a higher capital-labor ratio than an unregulated firm would use to produce the same output." Baumol and Klevorick also discuss the issue of which type of firm would produce a larger output, regulated or unregulated. This issue is outside the scope of this paper.

Having stated the A-J hypothesis correctly, the counter-arguments made by Joskow are briefly developed. Following this, the survey of the empirical studies will be presented.

## II. A Behavioral Model of Regulation<sup>6</sup>

The Averch-Johnson hypothesis follows directly from the regulatory mechanism employed in their model and the assumption of profit-maximizing behavior by the firm. The A-J analysis assumes perfect certainty and implies that regulation is continuous. Regulators are taken to be so inept or single-minded that they allow a rate base greater than the cost-

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<sup>5</sup>Baumol and Klevorick [6], pages 179-180.

<sup>6</sup>Other writers besides Joskow [13] have challenged or modified the A-J hypothesis on theoretical or institutional grounds. On the issue of regulatory lag, see Bailey and Coleman [3] and Klevorick [14]. On the issue of uncertainty, see Myers [15], Corey [8]. For other extensions see Bailey and Malone [4] and Bailey [2]. For a precise mathematical development, see Takama [21]. Peles and Stein [25] provide analytical framework under uncertainty. They find that the A-J capital bias depends critically on the nature of the uncertainty.

minimizing rate base.<sup>7</sup> Some authors have extended the A-J analysis by changing the nature of the regulatory process.<sup>8</sup>

Joskow's 1974 paper [13] challenges the A-J paradigm on the grounds that regulatory authorities do not operate in the simplistic, single-minded manner that A-J assumed, and on the grounds that firms are not strict single-period profit-maximizers. Joskow's approach is behavioral; the regulators are viewed as seeking to avoid criticism and public dissatisfaction, while the firm is viewed as seeking long-run profit maximization in a loose sense.<sup>9</sup> The regulators are therefore more concerned with nominal price levels (increases in which cause public dissatisfaction) than with profit levels. They allow firms to keep any profits above or below the "allowed" level and only intervene when the firm asks for a nominal price change.

Of course, regulators are concerned with quality of service and perhaps other aspects of the firm's production function such as pollution abatement. But the nominal price of service is the main focus of public attention and so becomes

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<sup>7</sup> Many of the articles arising from the A-J paper assume continuous regulation; actually, some A-J capital-bias tendency would be expected without continuous regulation if the investment horizon is long vis-a-vis the regulatory review horizon.

<sup>8</sup> In particular, the study of Baron and Taggart [5], presented in section 3, and Baumol and Klevorick [6].

<sup>9</sup> Firms may seek a certain rapport with the regulators that involves actions that do not appear to be consistent with pure profit maximization. Such a rapport may elicit lenient treatment by the regulators during critical periods for the firm.

the main focus of the regulator. As long as firms do not request price increases, regulators can stay out of the public limelight. In Joskow's framework, regulators do not monitor the earned rates of return of the firms in their jurisdiction. Only when firms seek price increases must the commission fix an allowed rate of return which is then translated into a new nominal price.

In sharp contrast to the continuous regulation of rate of return that is the cornerstone of the A-J analysis, Joskow views the regulatory process as basically passive until the firm is forced to come before the commission to seek a price change. The important difference between these two alternative regulatory scenarios is in terms of the optimal firm behavior they imply. Since Joskow's model of regulation allows firms to keep any profits they can earn in excess of the allowed rate, firms will generally seek to minimize costs. Given a period of stable or declining average costs it would be expected that:

- 1) No firms request price increases (but perhaps some request price decreases), and
- 2) Firms will earn higher rates of return than the allowed rate.

Only in periods when costs are rising (due to perhaps inflation, diseconomies of scale, or environmental regulation), when firms are constantly requesting price increases as their rates of return fall below the rates they expect to be allowed,

does the A-J model seem to have operational content.<sup>10</sup>

Given an investment horizon longer than the regulatory horizon, uncertainty with respect to demand and regulatory strictness, and reasonably stable input prices, most firms would not engage in the capital-bias behavior of the A-J model. Joskow has compiled some evidence to show that regulatory activity corresponds to periods of changing costs.<sup>11</sup> Specifically, he notes two periods of substantial activity in electric utility rate of return requests: 1957-62 and 1968-74 (this period is still with us). Between 1962 and 1968 there were very few requests for price increases. This period corresponds to a steadily declining cost of service in this industry. Further, Joskow shows a price and rate of return data that support the model of regulation that he has proposed and contradict the implications of the A-J model.

To reiterate, the A-J model is technically correct based on the regulatory process described in the article. Joskow's contributions is to show how sensitive the model's results may be to changes in the assumed regulatory process. We turn now to some of the empirical research that has been done on the A-J hypothesis with this background material in mind.

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<sup>10</sup>The A-J tendency might be further mitigated by the regulators' ability to detect the capital-bias behavior of the firms.

<sup>11</sup>See Joskow [13], pp. 305-311.

## Review of the Empirical Investigations of the A-J Hypothesis

There have been several attempts to test the A-J hypothesis. These have mainly been of two types--attempts to measure  $\lambda$ , the regulatory constraint Lagrangian multiplier, and attempts to test a corollary to the A-J hypothesis that  $dk/ds < 0$ .<sup>12</sup> Most of the studies use fairly obvious measures for the variables in the estimating equations such as total labor hours or number of employees for labor input, and total wage bill divided by number of employees for wage rate. Only where these variables are not obvious or lead to estimation problems will they be mentioned. The last study to be reviewed (Barron and Taggart) is a significant departure from the A-J model in its development, but leads to relationships that may be used to test the A-J hypothesis. A tabular summary of the results from the papers reviewed here is provided in Table 1. We will begin with an early study that approaches the problem in a fairly simplistic manner.

### Moore

Moore's study rests on a rather heroic assumption--municipal electric companies operate efficiently. Given this assumption, Moore ran several "capital-bias tests" by regressing certain capacity measures on output measures and a public vs. private dummy variable. The dummy variable's coefficient served as the test for A-J bias. For example, one regression was total capacity on peak demand and the dummy variable. A dummy coefficient different from zero would support A-J. In

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<sup>12</sup>This theorem is proved in Baumol and Klevorick [6] pg. 175.

a more sophisticated regression, per kilowatt capacity costs were regressed on plant age, fuel type, capacity, and the dummy variable for a sample of 167 plants.

All of Moore's tests refuted the A-J hypothesis. However, the confidence one could have in such tests is low. First, it is not clear that Moore avoided the well-known dummy variable trap. Second, the presumption that public utilities do not engage in capital-bias behavior is certainly open to question. Public firms may be run by persons whose personal satisfaction is positively related to the size of the enterprise they manage. Secondly, these persons may face a risk-return tradeoff in their jobs as managers that leads them to over-employ capital to avoid possible capacity shortfalls. Third, city officials and plant managers may have an easier time increasing the size of a bond issue (to buy capital equipment) than increasing the size of the city payroll. Fourth, municipals can issue tax-exempt bonds, providing them with a capital subsidy that may encourage higher capital intensity than private firms.

### Spann

In one of the very first empirical investigations Spann tested the A-J hypothesis by deriving the factor share equations from a trans-log production function with three inputs. This required the assumption of constant elasticity of demand. The profit constraint multiplier,  $\lambda$ , is an argument in the factor share equations. By estimating

these equations Spann could test  $H_0: \lambda = 0$ ;  $H_a: \lambda \neq 0$ .<sup>13</sup>

Spann noted that his formulation was deficient in that  $\lambda$ , which is a firm-specific endogenous variable, is treated as a data-wide exogenous parameter. This is because  $\lambda$  is not directly observable. (Cowing's study [10] gets around this problem and is a more satisfactory test.) The parameter  $\lambda$  in Spann's study must be viewed as an average value across the sample data.

There were two data sets employed. One was firm data for 24 large electrics in 1963 and the other was plant data on 35 new steam plants from 1959-63.

Spann used a constant cost of capital across the firms in his study. The capital input was measured two ways: megawatt capacity and book value (plant, land, equipment for the plant data set and total assets for the firm data set). Fuel input was measured in BTU's, and the price of fuel in dollars per BTU. The allowed rate of return was estimated by the three-year average of earned rates of return for 1961-63. As Smithson [18, p. 573] points out, this may bias the results in favor of the alternative hypothesis  $\lambda \neq 0$ .

A non-linear search procedure was used to find the value of  $\lambda$  from the capital and fuel share equations. The results of this procedure yielded a value for  $\lambda$  significantly different from zero for both sets of data and under both definitions of

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<sup>13</sup>Actually Spann tested two things--profit-maximization and the A-J bias. But to test A-J, he must, of course, assume profit-maximizing firm behavior.

capital input. These results are supportive of the A-J hypothesis.

The treatment of  $\lambda$  as a single-valued exogenous parameter introduced a specification error that biased Spann's results. Also, Spann's estimating equations contained input quantities as explanatory variables. Since these are clearly endogenous variables to the firm, simultaneous equation bias is present due to failure to estimate the entire system of equations for constrained profit maximization. Spann's result in support of the A-J hypothesis must be evaluated in light of these econometric difficulties.

#### Courville

Courville argued that the provision of electricity really involves three separate activities: generation, transmission, and distribution. The latter two were assumed to be produced under conditions of fixed input proportions, and thus not subject to the capital bias hypothesis of A-J. For this reason, Courville focused his study on the generation production function.

Courville assumed a Cobb-Douglas production function with capital input measured by the dollar cost<sup>14</sup> of equipment and construction. He also included variables to measure variations in capacity utilization across firms since load characteristics

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<sup>14</sup>Courville also ran the regression with deflated capital cost data. His results were not very consistent, probably due to errors in the price index used. His undeflated results are presented here.

will affect the observed fuel-capital utilization relations.

Courville fitted data on the first year of operation of steam generating plants to his Cobb-Douglas function. The data were broken down into "vintage" periods to capture differences in technology over the sample. In each period the coefficient of labor input was not significantly different from zero and labor input was excluded from the final models. The periods and sample sizes for the final models were:

<u>period</u>	<u>sample size</u>
1948-50	28
1951-55	42
1960-66	39

The Cobb-Douglas function employed yields a very straightforward test of the A-J hypothesis since the ratio of marginal products is so easy to find. Courville directly tested the A-J model by determining whether the data supported  $\frac{MP_K}{MP_L} < \frac{r}{w}$ . His results confirmed the A-J capital bias for all periods, contrary to the Joskow analysis. Courville also made estimates of the resource costs of the A-J bias and found these to be rather small ([9], p. 70).

Courville's procedure suffers from a common error of the A-J empirical work--simultaneous equation bias. His Cobb-Douglas function has explanatory variables that are endogenous to the firm (factor inputs); estimating this single production function equation instead of a system of equations that jointly determine the factor inputs and output lead to biased estimates of the coefficients. This problem invalidates Courville's

results.

### Boyes

Boyes' study is similar to Spann's in direction. He specified a four-input Constant Ratio of Elasticity of Substitution production function to derive the input demand functions. The regulatory constraint parameter is  $\theta$ . As in Spann's paper, the A-J hypothesis is tested by  $H_0: \theta = 0$ ,  $H_a: \theta \neq 0$ . Again, in this type of framework  $\theta$  will be an average value for the sixty firms in the data set. (Observations were over the period 1957-1964.)

The four-input CRES function is a more flexible function than either CES or Cobb-Douglas. It allows for different elasticities of substitution between each pair of inputs. Maintenance is the fourth input besides capital, labor and fuel. This formulation allows for differences in the amount of capital input, due to say climate differences, to be considered in the model, as maintenance and capital inputs are clearly substitutes.

The input demand functions contain  $\theta$  as a parameter.  $\theta$  must be identified before the other parameters may be estimated. Boyes' procedure was to select a  $\theta$  value (recall  $0 < \theta < 1$ ) and then perform 2-stage least squares on the input demand function. Repeating this over the range of  $\theta$  values, he selected that  $\theta$  value which maximized the likelihood function from the capital input equation. The parameter estimates are thus maximum likelihood estimates.

The key parameter is  $\theta$ . Boyes' procedure yielded a value

for  $\theta$  that was not significantly different from zero. Therefore, Boyes' results do not support the A-J hypothesis.

Boyes also found that the relative magnitudes of elasticities of substitution were  $\sigma_{K,F} > \sigma_{F,L}$  and  $\sigma_{K,M} > \sigma_{L,M}$ , where  $\sigma_{i,j}$  is the elasticity of substitution of inputs  $i$  and  $j$  and the symbols represent capital, fuel, labor, and maintenance.

#### Hayashi-Trapani

Using both a Cobb-Douglas and CES production function, Hayashi and Trapani derive two sets of estimating equations for the capital-labor ratio of the regulated firm. One set is used to test the standard A-J capital bias as  $d(K/L)/dS < 0$ .<sup>15</sup> The other set is used to test the comparative statics properties of an alternative model that Hayashi and Trapani present. Basically this model specifies the regulatory constraint as  $R - wL - rk \leq \delta k$  where  $\delta$  is the regulated excess 'profit' over the cost of capital  $r$ .

Hayashi and Trapani use cross-sectional data on thirty-four electric firms. They ran their regressions with one of two different cost of capital variables. One was the embedded cost of debt, the other was the most recent cost of debt for the firm. This variable is clearly measured with error under either definition. Hence the variable  $w/r$ , which is used in

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<sup>15</sup> Hayashi and Trapani also test for the signs of other coefficients, such as \_\_\_\_\_ which A-J indicate should be less than zero. See Takayama [21], Westfield [22], or Baumol and Klevorick [6] for a development of this corollary to the A-J hypothesis.

their regression, is measured with error. Also, they measured the allowed rate of return by the average of the last three periods earned rates of return.<sup>16</sup> The sample period was 1965-69.

Some of their results for the standard maintained hypothesis that regulation focuses on  $S$  are consistent with the A-J hypothesis (the coefficient of  $S$  is negative and significant) under either definition of the cost of capital. Their results are also consistent with the corollary hypothesis that as  $S$  falls to  $r$ , usage of capital will increase. However, the coefficient of the variable  $w/r$  is generally positive implying that  $\delta(k/L)/\delta(w/r)$  is positive, in contrast with the A-J analysis.

To summarize, Hayashi and Trapanis' results, while supportive of both the original A-J model and their variant of it, are subject to criticism. The criticism by Smithson is the most damaging; coupled with the error in measurement of  $w/r$  this becomes more severe. In light of the period covered by their data and the Joskow argument, and the econometric problems, their results are questionable.

#### Peterson

Peterson tests the corollary to the A-J hypothesis that states:  $\frac{dK}{dS} < 0$ . In other words, the regulated firm will increase its use of capital as the regulator lowers the allowed rate of return towards the required rate of return.

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<sup>16</sup>Smithson [18] page 573, shows that this procedure may bias the empirical results in the direction of supporting the A-J hypothesis.

Because of the formulation of the model (Peterson sets up the firm's constrained optimization problem in terms of cost minimization), the actual hypothesis is that the change in capital's share of total cost for a change in  $s$ ,  $d(rK/c)/ds$ , is less than zero. The strong assumption that price and output are exogeneous to the firm is necessary both for this hypothesis to be equivalent to the A-J corollary and for Peterson's econometric approach to yield unbiased results. Since output price (and therefore quantity demanded) is a function of the capital input under the most common regulatory procedure,<sup>17</sup> this assumption is not particularly appealing. Therefore, Peterson's results are suspect due to a misspecification resulting in simultaneous equation bias.

Peterson's sample consisted of fifty-six steam generating plants that had experienced at least fifty-percent growth between 1960 and 1965. The observations on these plants were taken between 1966-1968. He used three variables to measure regulatory tightness to test his hypothesis that the share of cost going to capital increases with regulatory tightness. In one set of regressions he used dummy variables for state vs. local regulation and fair value vs. original cost rate base jurisdictions. The signs of the coefficients of these variables, where significant, were as predicted by the A-J model. The other variable used, in a different set of regressions, was

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<sup>17</sup> Regulated price is most generally set by first estimating variable costs for producing the expected demanded output. Then an amount  $sk$  is added as the return to capital. Next taxes are added and the sum is divided by the expected output. Variable cost and  $sk$  are both functions of the capital input  $k$ .

supposed to measure the difference between the allowed and actual rates of return (A-J's measure of regulatory tightness). However, Peterson made an error in the construction of the variable and it is measured with error.<sup>18</sup> Also, the use of actual rates of return instead of allowed rates for the construction of this variable may bias Peterson's results in favor of the A-J hypothesis.<sup>19</sup> In light of the three errors in Peterson's study, his findings in favor of the A-J hypothesis are questionable. Additionally, as the period of his study corresponds to a period during which Joskow suggests that the A-J bias was not at work, Peterson's results are even less compelling.

Finally, although the tightening of the regulatory constraint may lead to further capital intensity distortions, once the allowed rate of return dips below the actual cost of capital, firms would theoretically have a bias against using capital. Given the kinds of uncertainties in the industry (with respect to market demand and input prices), the implications Peterson's model are unclear.

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<sup>18</sup> Peterson incorrectly states  $s - PK = (Se - Pe)(1 - B)$  where PK and S are the cost and allowed return to capital, Pe and Se are the cost and allowed return on equity, B is the debt to rate base ratio. This equation is true only if the allowed return to debt is equal to the cost of debt. Since the embedded cost of debt is generally used in regulatory proceedings, the equality should be changed to an inequality:  $s - Pk < (Se - Pe)(1 - B)$  in the general case.

<sup>19</sup> See Smithson [18] page 573.

BTU's. The price of labor was average per worker salary, while the price of fuel was calculated on a per BTU basis. Both  $P_L$  and  $P_E$  were deflated to be consistent over the period.

Smithson's results did not confirm the corollary to the A-J hypothesis. He found that both  $(K/L)/s$  and  $(K/E)/s$  were not significantly different from zero. Smithson concluded that the degree of regulation is not a significant factor in firm's input usage decisions. He suggested that the contrary results of Hayashi-Trapani and Peterson were due to improperly using the actual rate of return as the allowed rate, instead of recognizing that for A-J these two rates are only equal in equilibrium.

#### Cowing

The approach taken by Cowing differed from previous studies. He used a form of the profit function for a regulated firm, called the unit-output-price (UOP) profit function, that allowed firm-specific estimation of the regulatory constraint Lagrange multiplier  $\lambda_i$ .<sup>21</sup> Basically, this approach requires that output price is exogenous to the firm; the profit function is then divided through by price. Cowing solved for the first-order constrained profit-maximization conditions to yield input demand equations. The parameter  $\lambda_i$  is an argument in these equations. The A-J hypothesis was tested by the values of  $\lambda_i$ .

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<sup>21</sup> $\lambda_i$  is an endogenous, firm-specific variable that is determined simultaneously with the capital, fuel and labor inputs. Since these are functions of the input prices,  $\lambda_i$  is also. To the extent that these prices vary across firms, so will  $\lambda_i$ .

Cowing obtained a set of estimating equations from the derived input demand relations from which  $\lambda_i$  had been eliminated. However,  $\lambda_i$  is retrievable from the system of equations on a firm-specific basis. The estimation procedure, based on a quadratic profit function, was a maximum likelihood, non-linear iterative search method.

The test of general A-J bias was tested by treating  $\lambda_i$  as constant across the sample of 114 new steam generating plants built between 1947-65. This test determined whether  $\lambda_i = 0$  for all plants ( $i = 1, \dots, 114$ ) in the sample. The test for each  $\lambda_i = 0$  separately was also conducted, under the assumption of an asymptotically normal  $\lambda_i$  distribution. The results of the first test were consistent with the A-J hypothesis in three of the four periods analyzed (1947-50, 1955-59, 1960-65)<sup>22</sup> The tests carried out on the individual  $\lambda_i$ 's yielded the following results:<sup>23</sup> (significantly different from zero at 5% level)

<u>Period</u>	<u>Results</u>
1947-50	1 of 21 firms
1955-59	12 of 26
1960-65	.17 of 23

These results are roughly consistent with Joskow's periods of regulatory activity. The constraint will be non-binding

<sup>22</sup> Certain other tests of the A-J model were conducted on the sample data. These tests arose from the application of the A-J regulatory framework to Cowing's quadratic UOP model. The results were mixed with respect to the A-J analysis. Cowing's conclusion was that the sample-wide results suggest general regulatory effectiveness.

<sup>23</sup> The sample size was reduced due to missing data.

( $\lambda = 0$ ) when the earned rate of return (his proxy for the allowed rate) is less than the allowed rate. The period 1949-53 Joskow identifies with rising costs which would lower earned rates below allowed rates of return and lead to increased regulatory review activity. Conversely, the period 1961-68 was a period of little formal regulatory review because earned rates were generally greater than allowed rates. Cowing's results reflect this by the higher proportion of significant  $\lambda_i$ 's in the 1960-65 period.

Cowing measured the cost of capital for each firm by the interest rate on the bond issue immediately preceding the construction of the new plant. This will bias the coefficient of this term downward and tend to bias the other terms coefficients up or down depending on their covariance with the error in the cost of capital variable. A second error of measurement was committed by using the earned rate of return for the allowed rate. A third error relates to the simultaneous equation bias introduced by assuming output price is exogenous. The effects of these three errors on the final results are uncertain.

#### Barron and Taggart

The above discussion of the empirical tests of the A-J bias may suggest that perhaps a more realistic model of regulation along the lines of the Joskow paper is needed. More specifically, a model that allows for mutual recognition and regulator-firm interaction with respect to more than the allowed rate of return seems in order. Barron and Taggart

provide such a model in which output price (not a rate of return) is the result of the regulatory process. Output price is postulated as being affected by the firm's choice of capital input. Regulatory lag is explicit in the model, and the regulator is not concerned with monitoring earned rates of return. The model postulates an uncertain demand to which the firm adjusts by varying the labor and fuel inputs applied to an ex post fixed capital stock. This formulation of the regulated firm's behavior is analytically more satisfying than the A-J model, and represents a significant contribution to the literature.

Barron and Taggart generate a model of regulation with a lag and solve for the stockholder preferred input relation. The A-J bias arises in their model only if the regulated price is influenced (positively) by the capital input level. If the price response is inversely related to changes in the capital input, undercapitalization will be the preferred policy.<sup>24</sup> This model's results are sensitive to the period of time between regulatory reviews, and the inter-review possibilities for capital adjustment. Briefly, if the regulatory 'lag' period is long and capital stock is easily (quickly, cheaply) variable, firms should exhibit cyclical behavior in their capital input levels. This behavior will be such that capital is 'low' between reviews and 'high' around review time, if price is

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<sup>24</sup>This is true given that the change in profit induced by the change in capital is of the same sign as  $\frac{\delta P}{\delta K}$ .

positively related to capital stock level. The behavior will be reversed if the regulators lower price as more capital is employed.

Barron and Taggart estimated two sets of equations based on their model of regulation. The first was a valuation model (single-equation) and the second was a set of factor share equations. Their data base was forty-eight electric utilities in 1970; estimation was done on all forty-eight firms and on subsets broken out by KWH sales and by the criteria used by Spann.<sup>25</sup> Their results show that the price expectation term,  $\frac{\delta P}{\delta K}$ , is significantly negative for all four groups. Their results also indicate that the marginal profit is positive, so that undercapitalization is suggested.

#### Summary

It would be satisfying to make a strong statement about the existence or non-existence of the capital bias behavior that the A-J model predicts. That is not possible given the present state of the art. While the studies that support its existence suffer from rather serious estimation problems, the evidence does not completely rule out the possibility that the bias exists. In fact, the most appealing model, that of Barron and Taggart, yields results that even suggest a reverse A-J effect. Perhaps we are left with the type of model Jaskow presented: sometimes we might observe an A-J bias, and sometimes

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<sup>25</sup> Those utilities which generate at least 90% of their distribution KWH and sell no more than 10% of their generation KWH for resale.

we will not. What we can say is that even if an A-J tendency to over-or under-employ capital exists, so many dynamic changes and uncertainties plague both the firm's decision-makers and our modeling attempts that the A-J tendency does not unambiguously reveal itself. Many researchers refer to the A-J effect as though it were a fact of life--self evident. These researchers have not done their homework, since the empirical tests (and alternative theoretical models) leave open to question the relevance of the A-J model for the real world.

TABLE 1A

Date	Name	Hypothesis	Methodology
1. 1970	Moore	if municipal firms are efficient producers, one can compare their capacity-utilization ratios to private firms. Higher ratios for private firms will indicate A-J capital bias.	simple linear regression with a dummy variable for private or public firms. (single equation)
2. 1974	Spann	if the capital-bias hypothesis is correct, it will be revealed by a positive value of $\lambda$ , the Langrange multiplier for the rate of return constraint.	factor share equations are derived from the A-J model with a trans-log production function. A constant elasticity of demand for output is assumed. A non-linear maximum likelihood search procedure is used to estimate $\lambda$ .
3. 1974	Courville	if the capital bias behavior exists, it exists only where there are possibilities for input substitution. Courville restricted his attention to generating plants for that reason. The hypothesis tested was that the ratio of marginal products of capital and fuel will be less than the corresponding ratio of their prices.	Using a Cobb-Douglas production function allowed easy derivation of the ratio of marginal products. The estimation technique was ordinary least squares on each of the sample groups; grouping was on a vintage basis.
4. 1975	Peterson	As the allowed rate of return falls, the share of cost going to the capital input increases, as do costs in general. In other words, as regulation becomes more restrictive ( $S$ approaches $P_k$ ), costs rise and dollars of capital input rise.	an estimatable cost function is developed from a second-order Taylor approximation of a general cost function. This is used to test the first part of the hypothesis of rising costs. An equation for the capital share of total costs is used to test the second part of the hypothesis. Both equations are estimated by ordinary least squares (single equation).

TABLE 1B

<u>Sample size</u>	<u>Time Record</u>	<u>Results</u>
6 34 private electric companies	1965-69	The results of the Cobb-Douglas specification are contradictory; while the Peterson-type hypothesis is confirmed, other A-J implications failed to be verified. Results from the CES production function specification are similar to the Cobb-Douglas results, but considerably weaker.
7 60 new steam plants	1957-64	The value of $\theta$ was not found to be significantly different from zero. This contradicts the A-J model of capital bias.
8 48 companies, split into 3 groups, by size and grouped together	1970	The results are that the price anticipation of an increase in capital is negative, and that regulation effectively keeps prices below the profit-maximizing level. These two results suggest that the A-J bias does not seem to be operating--in fact this study suggests undercapitalization.
9 30 companies	1966-70	The data do not support the corollary to the A-J hypothesis. Smithson suggests that the contradictory results found by Hayashi-Trapani and Peterson were due to a bias introduced by incorrectly indentifying the actual earned rates of return with the allowed rates of return.

TABLE 1B

Sample size	Time Record	Results
1 27 public companies, 49 private companies, 167 plants	1962	No evidence of A-J bias, perhaps even a bias in the other direction of inefficient munic- ipal firms.
2 Two data sets were used: A. 35 new steam plants B. 24 electric companies	A. 1959-63 B. 1963	$\lambda$ is significantly greater than zero for both data sets. A second test of an implied estim- ation constraint fails in the firm data. Over- all, the A-J bias is supported.
3 the sample was 99 new steam plants, broken into 3 groups: A. 26 B. 36 C. 37	A. 1948-50 B. 1951-55 C. 1960-66	The results support the A-J capital bias for all three periods.
4 56 steam plants	1966-68	Costs do seem to increase as regulation tight- ens--the first hypothesis is supported. As for the second hypothesis, Peterson's results also indicate that the share of capital input to total cost rises as regulation tightens. The A-J capital bias is supported.
5 114 new steam plants, split into four groups based on time of con- struction	1947-50; 1951-54; 1955-59; 1960-65	The results for show that for three of the four periods (not in 1951-54); this supports A-J in general. The results on show that the effectiveness of regulation in terms of the rate of return constraint varied substantially over the period. Cowing suggests that his data do not indicate whether A-J or Joskow explain observed behavior better.

<u>Date</u>	<u>Name</u>	<u>Hypothesis</u>	<u>Methodology</u>
9. 1978	Smithson	Smithson tests whether the corollary to the A-J hypothesis can be supported. The corollary is again as the degree of regulation tightens, the regulated firm will employ even more capital.	From a revenue function specified to be homogeneous, Smithson derives estimable input demand functions. These are partial adjustment equations to allow for possible lags in optimal input adjustments. A full-information procedure is used to estimate the system of simultaneous equations.

Date	Name	Hypothesis	Methodology
5. 1975	Cowing	this study was aimed at estimating $\lambda$ and $\lambda_i$ , the sample average and firm-specific Langrange multipliers, respectively. The A-J model shows that $\lambda > 0$ implies capital bias under the model's assumptions.	An estimatable cost function is developed from a second-order Taylor approximation of a general cost function. This is used to test the first part of the hypothesis of rising costs. An equation for the capital share of total costs is used to test the second part of the hypothesis. Both equations are estimated by ordinary least squares. (single equation)
6. 1976	Hayashi- Trapani	several implications of the A-J model are derived in this study. Among them is the hypothesis tested in the Peterson study above.	Ordinary least squares estimation is performed on the capital-labor ratio relationship developed in the paper for both Cobb-Douglas and CES-type production functions.
7. 1976	Boyes	If the A-J bices exists, the Langrange multiplier of the regulatory constraint, $\theta$ must be greater than zero.	Using a constant ratio of Elasticity of Substitution production function, Boyes derived the input demand relations. The estimation technique is a maximum likelihood procedure on a four-equation simultaneous system.
8. 1977	Baron- Taggart	If the firm expects that its choice of capital input will influence the regulated price, an A-J bias may result. This would occur if the regulated price responded positively to increases in capital input. A bias in the other direction (undercapitalization) will results if the price response is expected to be negative.	A Cobb-Douglas production function is coupled with a stochastic demand function to yield an exposite production function (stochastic). Input demand relations are dirived and substituted into a valuation equation to yield a single, estimatable reduced form of the optimality conditions. Also, a simultaneous equation technique is applied to the factor share equation derived.

## BIBLIOGRAPHY

1. Averch, H. and L. L. Johnson, "Behavior of the Firm Under Regulatory Constraint," AER, 52 (December 1962), 1052-1069.
2. Bailey, E. E., Economic Theory of Regulatory Constraint. (Lexington, Mass.: D. C. Heath, 1973).
3. Bailey, E. E. and R. D. Coleman, "The Effect of Lagged Regulation in an Averch-Johnson Model," Bell Journal, 2 (Spring 1971), 278-292.
4. Bailey, E. E. and J. Malone, "Resource Allocation and the Regulated Firm," Bell Journal, 1 (Spring 1970), 129-142.
5. Barron, D. P. and R. A. Taggart, Jr., "A Model of Regulation Under Uncertainty and a Test of Regulatory Bias," Bell Journal, 8 (Spring 1977), 151-167.
6. Baumol, W. and A. K. Klevorick, "Input Choice and Rate of Return Regulation: An Overview of the Discussion," Bell Journal, 1 (Autumn 1970), 162-190.
7. Boyes, W. J., "An Empirical Examination of the Averch-Johnson Effect," Economic Inquiry, (March 1976), 25-35.
8. Corey, G. R., "The Averch-Johnson Proportion: A Critical Analysis," Bell Journal, 2 (Spring 1971), 358-373.
9. Courville, L., "Regulation and Efficiency in the Electric Utility Industry," Bell Journal, 5 (Spring 1974), 53-74.
10. Cowing, T. G., "Profit Functions and the Estimation of Regulatory Effectiveness," Presented at the Winter meetings of the Econometric Society, December 1975.
11. Hayashi, P. M. and J. M. Trapani, "Rate of Return Regulation and the Regulated Firms Choice of Capital-Labor Ratio: Further Empirical Evidence on the Averch-Johnson Model," Southern Economic Journal, (January 1976), 384-398.
12. Johnson, L. L., "Behavior of the Firm Under Regulatory Constraint: A Reassessment," AER, 63 (May 1973), 90-97.
13. Joskow, P. L., "Inflation and Environmental Concern: Structural Change in the Process of Public Utility Price Regulation," Journal of Law and Economics, 17 (October 1974), 291-327.

14. Klevorick, A. K., "The Behavior of the Firm Subject to Stochastic Regulatory Review," Bell Journal, 3 (Autumn 1972), 632-644.
15. Meyers, S. C., "A Simple Model of Firm Behavior Under Regulation and Uncertainty," Bell Journal, 4 (Spring 1973), 304-315.
16. Moore, T., "The Effectiveness of Regulation of Electric Utility Prices," Southern Economic Journal, 36 (April 1970), 365-375.
17. Peterson, H. C., "An Empirical Test of Regulatory Effects," Bell Journal, 6 (Spring 1975), 111-126.
18. Smithson, C. W., "The Degree of Regulation and the Monopoly Firm: Further Empirical Evidence," Southern Economic Journal, 44 (January 1978), 568-580.
19. Spann, R. M., "Rate of Return Regulation and Efficiency in Production: An Empirical Test of the Averch-Johnson Thesis," Bell Journal, 5 (Spring 1974), 38-52.
20. Stigler, G. and C. Friedland, "What Can Regulators Regulate: The Case of Electricity," Journal of Law and Economics, 5 (October 1962).
21. Takayama, A., "Behavior of the Firm Under Regulatory Constraint," AER, 59 (June 1969), 255-260.
22. Westfield, F., "Regulation and Conspiracy," AER, 55 (June 1965), 424-443.
23. Zimmer, M. A., "Empirical Tests of the Averch-Johnson Hypothesis: A Critical Appraisal," Ed. Maddala, et al., in Econometric Studies in Energy Demand and Supply, (New York: Praeger Pub., 1978).
24. Callon, J. L., "Production Efficiency and Welfare in the Natural Gas Transmission Industry," AER, (June 1978), 311-323.
25. Peles, Y. C. and J. L. Stein, "The Effect of Rate of Return Regulation Is Highly Sensitive to the Nature of the Uncertainty," AER, 66 (June 1976, 278-289).