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AN ECONOMETRIC STUDY OF INDUSTRIAL WATER DEMAND IN BRITISH COLUMBIA

by: Steven Renzetti

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An economic study of industrial water demand in British Columbia

AN ECONOMETRIC STUDY OF INDUSTRIAL WATER DEMAND IN BRITISH COLUMBIA

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ABSTRACT

This report presents the results of the second phase of a study into the British Columbia manufacturing sector's water demands. The second phase extends the results of the first phase by employing a more sophisticated economic model and more advanced statistical techniques. Specifically, a system of water demand equations is estimated for each industry group rather than single equation water intake demand functions. As well, an instrumental variables approach is adopted in order to reduce the estimates' simultaneity bias and a hedonic model is introduced as a first attempt at incorporating water quality into the demand structure.

Empirical results are reported for four manufacturing sub-groups: Petro-Chemicals, Heavy Industries, Forest Products and Light Industries. Demand equations are derived from a water use cost function in Cobb-Douglas form. Intake price elasticities range from -0.12 (Petro-Chemicals) to -0.54 (Light Industry) and water intake elasticities with respect to final output range from 0.76 (Heavy Industry) to 1.9 (Light Industry). The cross price elasticity between water intake and recirculation is positive for all industry groups and ranges from 0.14 (Petro-Chemicals) to 0.26 (Heavy Industry). The results of this project demonstrate the substantial explanatory power of economic models and the influence of economic variables on industrial water use.

There still exist enormous gaps in the amount known concerning the economic nature of water demands in Canada. This study concludes with suggestions for further economic research.

RESUME

Ce rapport présente les résultats de la seconde phase de l'étude de la demande d'eau pour le secteur industriel de la Colombie-Britannique. Cette deuxième phase comprend une amplification de l'étude de la première phase et aussi l'utilisation d'un modèle économique plus sophistiqué et des méthodes de statistiques plus avancées. Plus spécifiquement, une serie d'équation de demande d'eau est estimée pour chaque group d'industrie plutôt qu'une équation de prélèvement d'eau pour chaque industrie. Aussi, une approche de variables instrumentals est utilisée pour réduire les estimations de biais de simultanéités et un modèle hédonique est introduit comme premier essai pour inclure la qualité d'eau dans l'encardrement de la demande d'eau.

Des résultats empiriques sont donnés pour quatre sous-groupes manufacturiers: notamment, les industries lourdes et légères, pétro-chimiques, et de bois. Les équations de demande sont dérivées d'une fonction de coût d'utilisation des eaux de façon Cobb-Douglas. Les elasticités de prix de prélèvement d'eau s'étendent de -0.12 (industries pétro-chimiques) à 0.54 (industries légères), et les elasticités de prélèvement d'eau relative au produit final parcourent de 0.76 (industries lourdes) à 1.9 (industries légères). L'elasticité croisé des prix de prélèvement et de recirculation d'eau est positif pour tous les groups d'industries et varie de 0.14 (industries pétro-chimiques) à 0.26 (industries lourdes). Les résultats de cette étude demontrent le pouvoir des modèles économiques et l'influence des variables économiques sur l'utilisation des eaux industrielles.

Il existe encore beaucoup de lacunes concernant les connaissances économiques pour le demande d'eau au Canada. Cette étude conclue avec des suggestions pour de plus amples recherches dans ce domaine.

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CHAPTER I
INTRODUCTION

A. Introduction

This paper presents the results of the second phase of an Inland Waters Directorate study of water demands in the British Columbia manufacturing sector. In the first phase of the study, information regarding industrial water use in British Columbia was discussed (Renzetti, 1986). As well, that report presented a theoretical economic model of industrial water demand and applied it to the British Columbia portion of the 1981 National Industrial Water Use Survey. The results of that exercise are summarized in the next section of this chapter.

The second phase of the project represents an extension of the economic and statistical methods used in the first phase. A generalized form of the economic model and more sophisticated statistical techniques are employed. More detail regarding these methods and how they represent advances over those used in the phase one study is provided in the third section of this chapter.

B. Summary of "Industrial Water Demand in British Columbia"

The first phase of this project had the following four major goals:

- i. review the professional literature relevant to the economics of industrial water demands
- ii. construct an economic model of industrial water demands
- iii. apply that model using the British Columbia portion of the Industrial Water Use Survey and report any results
- iv. determine what future studies to conduct and the methods to be used in them.

The review of the literature revealed that scant attention had been paid to the nature of water demands in North America. While a large number of studies have considered domestic water demands most of these have adopted overly simple functional forms and estimation procedures. Exceptions include Jones and Morris (1984) which employs an instrumental variables approach and Al-Quanaibet and Johnson (1985) which uses an OLS estimation model but employs a Stone-George utility framework to derive estimatible forms for demand equations. The municipal water demand literature is reviewed in Kindler and Russell (1984).

The literature concerning industrial water demands is significantly less complete than that addressing municipal water demands. Until recently the prevailing method of forecasting industrial water needs relied on the fixed coefficient 'water requirements' approach which assumed a fixed relationship between either water intake and output or water intake and the quantity of some other input (Boland, et al, 1983). DeRooy (1974) represents an earlier attempt at estimating industrial water demands using firm level data from the New Jersey chemical industry but that study suffers from an overly simplified model of input demand. Field and Grebenstein (1979) and Babin, Willis and Allen (1982) both estimate translog cost functions for U.S. manufacturing with water intake as one input. While employing a theoretically sound model of the industry's technology these studies' empirical results are weakened by the possible presence of aggregation and simultaneity errors. The latter may have occurred as a result of input prices being defined by the observed exposte average cost.

Before beginning an econometric study of industrial water demands in British Columbia an understanding of the physical characteristics of industrial water use is necessary. The British Columbia manufacturing sector's water intake for 1981 was 5600 million litres per day - representing 61 percent of all recorded water withdrawals in British Columbia (1981 Canada Water Yearbook). Of the total manufacturing intake figure, four industries (Primary Metals, Paper and Allied Products, Chemical and Chemical Products, and Petroleum and Coal Products) account for 95 percent. As well, most industrial water use is for cooling, condensing and steam generation[1] and most water intake is from private sources rather than public utilities. The latter observation is important as it implies that the provincial water licence fees are the only external price for water many British Columbian manufacturing firms face. As well, the predominance of private intake systems suggests that water use costs may be a small fraction of the average manufacturing firm's operating costs. This is indeed the case; in 1981 water use costs represented no more than 3 percent of operating costs for British Columbia manufacturing industries[2].

The input demand model used in the first phase of the project was derived from the assumption that manufacturing firms are cost-minimizers. As a result of this behavioural assumption, the model of water intake demand emphasized the prices of all inputs (including the price of water intake) and the level of output as variables explaining water intake demand. Specifically, water intake demand was modeled as a function of the following: the prices of water intake, water treatment, water recirculation and water discharge; and the level of output. While several constructed price proxies were employed none of these adequately dealt with the simultaneity bias present due to prevelance of block rate water price structures and due to the use of observed average cost as one proxy for price. These problems are discussed in more detail in Chapter four of the project's first report.

Despite the simplified estimation model employed, some interesting empirical results were obtained. These were reported in Chapter six

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1 In addition to using water for cooling or for process some large manufacturing firms use water to generate their own electricity. This facet of water use is not considered by this project.

2 This ignores the cost of water for hydroelectric generation.

of the report. All of the two digit SIC level industries studied except Clothing and Textiles showed the expected inverse relationship between quantity of intake water demanded and intake price and the expected positive relationship between water intake and firm output. Water intake own price elasticities ranged from -0.01 for Primary Metals to -1.7 for Petroleum and Coal Products.

In order to estimate how industrial users valued intake water the estimated demand equations were used to derive approximate net and gross willingness-to-pay figures. Not surprisingly, these estimates turned out to be quite low; ranging from $0.9 per 1000 m^3 for Primary Metals to $48 per 1000 m^3 for Food and Beverage Products.

C. Purpose of the Second Phase

The purpose of the second phase of this study is to improve upon the empirical results obtained during the first phase. The use of more general economic models and more sophisticated statistical methods will lead to the generation of more defensible empirical results. Several methodological changes have been adopted.

First, the organization of the data will change. Because a more sophisticated statistical model is used a larger number of observations is required for each estimation. Thus, the estimation will be done at a higher level of data aggregation. Details are provided in the next chapter.

The second extension stems from the expansion of the theoretical model to include endogenous input prices, the quality of inputs and the joint determination of input demands. These changes to the theoretical model of industrial water demands will allow the consideration of block rate water prices and water inputs of varying quality.

The third extension involves the estimation procedure to be used. An instrumental variable approach will be used to deal with the potential simultaneity bias introduced by using the observed average cost as a proxy for intake price. In addition, because the theoretical model views water demands as part of a system of interrelated input demands, all of the input demand equations will be estimated as a system of simultaneously determined equations.

The rest of this report is organized as follows. Chapter two presents the data and theoretical economic model of industrial water demand. The estimation model and statistical methods are discussed in Chapter three. Chapter four presents the empirical results and chapter five concludes with a summary and suggestions for further study.

CHAPTER II
DATA AND ECONOMIC MODEL

A. Introduction

In this Chapter two items will be discussed. First, the data set used for this study will be outlined. Second, the economic theory of input demand which underlies the estimation model will be presented briefly.

B. Data

In 1981 Environment Canada, in conjunction with Statistics Canada, carried out the Industrial Water Use Survey. Questionnaires were sent to almost 5,000 manufacturing firms requesting detailed information on their uses of and expenditures on water. Environment Canada received approximately 3,300 responses from all over Canada and these were coded into a computer file. For this study only the set of responses from the British Columbia manufacturing sector were used. Table 2.1 provides a breakdown of the 372 responses from British Columbia into the four "manufacturing subgroups" by which the empirical results of this investigation will be reported. Table 2.1 also indicates which two-digit SIC code manufacturing industries are included in each of the "manufacturing subgroups".

The Industrial Water Use Survey contained questions regarding the quantities and expenditures on water intake, treatment, recirculation and discharge. As well the survey identified the source of intake water and the point of discharge for waste water. This information is important for determining water rental cost based on provincial and municipal licensing regulations. The survey also asked for employment data and information regarding the firm's product and production process.

TABLE 2.1

Organization of Observations from British Columbia
National Industrial Water Use Survey

Manufacturing Sub Group	Industry (and SIC)	Number of Observations
1) Petro Chemicals	Chemicals (37) Petroleum and Coal Products (36)	47
2) Heavy Industry	Mineral Products (35) Transportation Equipment (32) Metal Fabricating (30) Primary Metals (29)	91
3) Forest Industry	Paper and Allied Products (27) Wood Products (25)	104
4) Light Industry	Textiles (18) Rubber and Plastics (16) Food and Beverages (10	130

In addition to the Industrial Water Use Survey there are two other sources of water cost data. First, the provincial Ministry of Environment supplied information on provincial water rental fees and water licence fees for firms with private intake sources. The British Columbia Water and Waste Water Association (1984) provided detailed information on municipal water rate structures throughout British Columbia. These two sources were valuable as they allowed intake water costs to be calculated for a significant portion of those firms which did not supply cost information. Finally, Statistics Canada publications supplied data on the value of output for British Columbia manufacturing industries and on expenditures for non-water inputs. The various data sources described here provide an excellent source of information regarding industrial water use in British Columbia.

C. Economic Model

In order to model the various segments of the British Columbia manufacturing sector it is assumed that each of them can be characterized by a positive, strictly quasi-concave, monotonic and twice differentiable production function of the following general form:

$$(1) \quad Q = f(WI, WT, WR, WO, X)$$

where Q is output; WI, WT, WR and WO are the quantities of water intake, water treatment, water recirculation and water discharge, respectively; and X refers to a vector of non water inputs such as labour and capital. The function represented in equation (1) gives the maximum output of each manufacturing sub group for any specified level of the inputs[1].

The cost function relates the prices of the inputs and the level of production to the total cost of production. Given the form of equation (1), the cost function will be of the form:

$$(2) \quad C = g(P_{WI}, P_{WT}, P_{WR}, P_{WO}, P_X, Q)$$

where the P_i refers to the price of the i^{th} input. Under the restrictions placed on the production function, it can be shown that the cost function will be strictly quasi-concave, positive, non decreasing in prices and twice differentiable (Diewert, 1975).

Because the National Industrial Water Use Survey collected data only on water use it would be very difficult to consider inputs other

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1 Economic theory dictates that a firm's production function satisfy certain properties. For example, if more inputs are used then more output is possible. The assumed characteristics ensure that the mathematical expression used to depict the production function possesses the features required by economic theory (for a further discussion, see Varion, 1981, ch. 1). These assumptions are also necessary to ensure that a cost function dual to the production function exists (Diewert, 1975).

than these in the estimation model. As a result, it is assumed that the cost function is separable in the water inputs. That is, the cost function is assumed to have the following structure:

$$(3) \quad C = g\ (\phi\ (P_{WI},\ P_{WT},\ P_{WR},\ P_{WO},\ Q),\ X,\ Q)$$

where the function $\phi(\quad)$ is a sub-cost function. The implication of the assumed structure of the cost function is that the elasticities of substitution among the components of $\phi(\quad)$ are independent of the levels of the quantities of the other inputs in $g(\quad)$. As well, the assumed separability implies that all of the inputs in $\phi(\quad)$ have the same elasticity of substitution with inputs not in the sub-cost function, $\phi(\quad)$. The reader is referred to Berndt and Christensen (1973) for a detailed discussion of the implications of assuming separability in the structure of the cost function.

There are other limitations of the form assumed for the cost function in equation (2). By specifying that the cost function is a function of the exogenous prices it is being assumed that the firm's (or industry's) demand for the input has no impact on the input's price and that each unit of the input is qualitatively the same. In the context of estimating the sub-cost function $\phi(\quad)$ for British Columbian manufacturing industries, it is unlikely that either of these assumptions is reasonable and that to maintain them might lead to a flawed estimation procedure. The reasons for mistrusting these assumptions (exogeneity of input prices and uniformity of input quality) and the ways in which the basic model of the cost function can be extended are discussed below.

There are several possible reasons why the price of an input would not be exogenous to the firm. A firm's (or industry's) demand for an input could be large relative to the size of the entire market and this would suggest some degree of price setting power by the firm (or industry). Alternatively, the supply curve for the input could be non-horizontal and, as a result, the marginal price of the input would be a function of the quantity traded. This is usually the case for inputs like water or electricity which are priced in block rate structures by public utilities (Kindler and Russell, 1984, Ch. 1).

As an illustration of how a non horizontal supply function could be incorporated into the model of the cost-minimizing firm, consider the following simple example of a firm optimizing over two inputs, X_1 and X_2 and assume that p_1 is exogenous to the firm while $p_2 = p_2(X_2)$ is the (inverse) supply function for X_2. The firm's problem is the following:

$$(4) \quad \min_{X_1, X_2} L = p_1 X_1 + p_2(X_2)\, X_2 + \lambda\, (Q_0 - f(X_1, X_2)\,)$$

where λ is the Lagrangian multiplier and Q_0 is some arbitrary level of output. Solving the first order conditions for this problem yields a system of two interrelated demand equations:

$$(5) \quad X^*_1 = \phi_1\, (p_1,\, p_2,\, \eta_2,\, Q_0)$$

$$(6) \quad X^*_2 = \phi_2\, (p_1,\, p_2,\, \eta_2,\, Q_0)$$

where the star (*) indicates the optimal amount of the input and η_2 is the price elasticity of supply for input two.

An alternative approach to the reduced form method of adapting the models is available. If the specific form of the interaction between the firm's demand and the price of the input is unknown then the model of the firm's input demands can be used in an unaltered form but an Instrumental Variables approach is used in the estimation of the cost and demand functions. This procedure will be discussed in the next chapter.

The second major limitation of the cost function as expressed in equation (3) is that it does not allow the quality of any of the inputs to be included in the model. In many instances the quality of an input is a very important consideration for the firm. Consider some examples: workers can differ as to the amount of relevant job experience they possess, types of fuel oil can differ in their BTU/gallon ratings and different water bodies can differ in their alkalinity, acidity or BOD level. In the case of an input which has a single quality parameter (for example, 'years of experience' for workers) then it may be possible to redefine the input rather than try to incorporate a quality parameter into the demand model. In the example of workers, the model might be reformulated so that the firm has separate (but interrelated) demands for experienced and inexperienced workers. This redefining of the input procedure is not feasible in all cases and in these instances the qualitative characteristic(s) of the input must be explicitly incorporated into the demand model.[2]

There are at least two reasons why it would not be feasible in general to expand the vector of inputs in order to encompass the quality dimension. First, while this approach may be appropriate for inputs with well defined qualities such as drill presses or fuel oil it may not be satisfactory for goods characterized by a continuum of qualities. Not only would the vector of inputs become so large as to make econometric estimation of a cost or production

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2 Rosen (1974) provides a detailed discussion on the theoretical aspects of the topic while Spady and Friedlaender (1978) consider this problem in the context of an applied economic model.

function infeasible, but also, if quality is truly continuous, there is no convenient way to define a quality-specific input (cf. Spady and Freidlaender, 1978, p. 159-61). The second reason stems from Rosen's original view of goods (i.e. inputs or outputs) as bundles of quality characteristics. Rosen then developed a theory of hedonic prices which emphasizes that bundled goods may be indivisible; that is, not subject to costless 'unbundling and repackaging' (Diamond and Smith, 1985, p. 281). The above reasoning suggests that a more appropriate way to model inputs with important and discernible characteristics would be to model explicitly the relationship between the productivity of the input and its attributes. Thus, the primal production function in equation (1) could be rewritten:

$$(7) \quad Q = f\,(WI\,(\alpha_1, \alpha_2), WT, WR, WO\,(\beta_1, \beta_2), X)$$

where α_1, α_2 and β_1, β_2 are discernible quality characteristics for intake and discharge water, respectively. For example α_1 could measure acidity and α_2 could measure hardness. The resulting dual cost function then would have the following structure:

$$(8) \quad C = g\,(P_{WI}\,(P\alpha_1, P\alpha_2), P_{WT}, P_{WR}, P_{WO}\,(P_{\beta 1}, P_{\beta 2}), Px)$$

where, now, the P_{WI} ( ) and P_{WO} ( ) act as sub aggregator functions[3] and $P\alpha_1$, $P\alpha_2$, $P_{\beta 1}$, and $P_{\beta 2}$ are the shadow prices of their respective quality attribute. The derivation of these shadow prices is discussed in the next chapter.

There are several important economic variables which may be derived from the estimated cost function. As indicated in the above paragraph, shadow prices for alternative qualitative characteristics

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3 Readers not familiar with the relationship between the economic theories of duality and separability are referred to Berndt and Christensen (1973), and Blackorby, Primont and Russell (1977).

(in this case different forms of water treatment) can be derived. In addition, input demand equations can be obtained using Sheppard's Lemma (cf. Varian, 1978, p. 32) in the following manner:

$$(9) \quad x_i\,(p,Q) = \frac{\partial C\,(p,Q)}{\partial P_i}$$

where x_i (p,Q) is the conditional demand for input i, p is a vector of input prices, Q is the level of output, C(p,Q) is the cost function and P_i is the i^{th} factor's price.

Finally, a set of elasticities can be derived from the estimated cost function. The inputs' own price and output elasticities are easily derived from parameter estimates. As well, the relationship between any pair of inputs can be approximated through the construction of Allen partial elasticities of substitution. These economic variables show the responsiveness of an input ratio (eg. capital to labour) to an incremental change in the ratio of the inputs' prices. Formally, this can be expressed as the following (Varian, 1978, pp. 70-72):

$$(10) \quad E_{ij} = \frac{\partial \left(\frac{x_i(p,Q)}{x_j(p,Q)} \right)}{\partial\,(w_i/w_j)} \cdot \frac{\frac{w_i}{w_j}}{\frac{x_i}{x_j}}$$

which, by using the economic theory of duality, can be shown to equal the following expression (Berndt and Wood, 1975):

$$(11) \quad E_{ij} = \frac{C(w,Q) \cdot C_{ij}(w,Q)}{C_i(w,Q) \cdot C_j(w,Q)}$$

where: $C_i\,(w,Q) = \frac{\partial C\,(w,Q)}{\partial P_i}$ $C_{ij}\,(w,Q) = \frac{\partial^2 C\,(w,Q)}{\partial P_i\,\partial P_j}$

These elasticities are very valuable in characterizing the firm's technology as they can indicate the degree of substitutibility or complementarity between pairs of inputs.

The economic model of the firm's technology and the firm's decision making as it is described in equation (8) has several features which make it attractive for use in water demand modeling. The behavioural assumption of cost minimizing behaviour which is implicit in the construction of equation (8) implies that the firm simultaneously chooses the optimal levels of all of its inputs. The optimal quantity of water intake, for example, is then a function of the prices of all of the inputs the firm is employing. Secondly, the cost function in equation (8) is quite general as to the relationships among inputs. Whether any pair of inputs are complements or substitutes is an empirical question. Finally, the cost function is specified to allow for the incorporation of the qualitative features of inputs (particularly water) into the firm's decision making process. This is a valuable feature as for many firms the quality of process water is an important choice variable.

D. Conclusions

This chapter has presented the data set and the economic model to be used in this project. The data set is national in scope and provides plant-specific observations on the manufacturing sector's water use and expenditures. The data set also provides information on the degree of water treatment conducted by firms. The economic model presents a theory of firm decision making based on the idea of cost minimization through the simultaneous choice of input demands. The model can be extended to allow for nonexogenous input prices and to incorporate water quality into the firm's choice set. Having specified the general theoretical model it is now necessary to detail the econometric methods to be employed.

CHAPTER III
ESTIMATION MODEL

A. Introduction

This chapter will detail the estimation models and procedures used to apply the theoretical economic model to the 1981 British Columbia portion of the Industrial Water Use Survey. The specification of an estimatible form for the water use cost function is discussed in the next section. In the third section the generation of the instrumental variable for the intake price and the hedonic price function for the treatment price is discussed.

B. The Water Use Cost Function

For the purposes of estimation it is necessary to employ a specific functional form for the cost function described by equation (8) in the previous chapter. The Cobb-Douglas functional form is chosen. While the Cobb-Douglas is not a flexible functional form[1], it does allow both the estimation of demand equations as a system and the estimation of the inputs' own and cross price elasticities and own output elasticities.

The water use cost function being considered has four input prices and the level of output as its arguments. The four input prices are the following: price of water intake (PIN), price of water treatment prior to use (PTRT), price of recirculation (PRCR) and price of treatment prior to discharge (POUT). The four factor Cobb-Douglas cost function may be written.

$$(1)\ C = \pi_i\, P_i^{a_i} + \Sigma_i\, P_i\, Q^{b_i}$$

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1 Diewert defines a flexible functional form as one which can provide second order approximation to an arbitrary twice differentiable function. The translog (Christensen, Jorgenson and Lau, 1971, 1973) satisfies this property but initial estimates using this form were unsuccessful; in particular, the second order terms were insignificant, suggesting a Cobb-Douglas form.

The second term on the right-hand side of equation (1) allows the Cobb-Douglas to be non-homothetic as the level of output appears in each input demand equation. Using Sheppard's Lema (Diewert, 1974) allows the system of input demand equations to be derived from equation (1):

(2) $$\frac{\partial C}{\partial P_i} = X_i = (a_i P_i^{a_j-1}) \pi_j P_j^{a_j} + Q^{b_i}$$
for i=1..4 and j not equal to i

or, after taking the natural log of both sides of equation (2),

(3) $$\ln X_i = \ln(a_i) + (a_i-1)\ln(P_i) + \sum_j a_j \ln(P_j) + b_i \ln(Q)$$
for i = 1...4 and j not equal to i

where X_i is the cost minimizing conditional demand for the i^{th} input.

A major limitation of the Cobb-Douglas form is that it assumes that all of the elasticities of substitution between inputs are equal to one[2]. Nonetheless, cross-price elasticities (conditioned on a constant level of output) may be derived. From equations (3) the ij^{th} cross price elasticity is simply equal to the estimate of the parameter (a_j) from the i^{th} equation. As well, each input's own output elasticity can be derived from the estimated parameter (b_j).

The input price variables will be generated as follows: average cost will serve as a proxy for prices of recirculation and treatment prior to discharge while intake and treatment prior to use will be generated using instrumental variable and hedonic methods, respectively. The two latter procedures will be explained in the next section. Total employee hours per year will be used as a proxy for the output variable. The system of the four demand equations as

2 In order to see this, apply equation (11) from the previous chapter to equation (1) above.

described in equation (3) will be estimated using an iterative two stage least squares procedure with the appropriate homogeneity and cross equation symmetry conditions imposed. All estimation will be conducted using the computer econometrics package SHAZAM (White, 1978). By comparing equation (3) to equation (1) it is apparent that estimating the system of demand equations is equivalent to estimating the cost function and all but one of the demand equations (due to the adding-up property of demand equations as seen in Euler's theorem - cf. Varian, 1978, p. 269).

Thus, the structure of the water use technology for each of the four British Columbia sub manufacturing groups will be characterized by estimating the system of four input demand functions in equation (3). In order to do this the estimation model must be placed within a stochastic framework. It is assumed that the deviations of the observed quantities from the optimal input levels result from errors in cost minimization by the firms. Thus, additive error terms are appended to each of the estimated equations. These error terms are assumed to be independently and identically normally distributed with mean zero and a constant, non-singular variance - covariance matrix.

C. Instrumental Variable and Hedonic Models

If the input prices were truly exogenous to the industry then the above discussion of the estimation model would be sufficient. But that is not the case when considering British Columbia water demands. The intake price is potentially endogenously determined because it is approximated by the observed exposte average cost of intake and because most firms in the sample face declining block rate price structures for their intake water. The latter situation implies that the marginal price of water is jointly determined with the quantity of water withdrawn. In the context of estimating water demand equations, this further implies that the price regressor term is not independent of the disturbance term. Using OLS techniques in this instance may lead to biased parameter estimates (Maddala, 1977, ch. 11; Judge, et al, 1982, ch. 17).

In order to avoid generating biased parameter estimates an instrumental variable method will be used for the intake price variable. A price instrument will be created by regressing the observed average cost of intake water against a set of instruments which are assumed to be exogenous to the firm (and, therefore, orthogonal to the error term) but correlated with the dependent variable. Following Taylor (1975) and Jones and Morris (1984) the structures of the block rate schedules facing British Columbia manufacturing firms will be used to create the regressors.

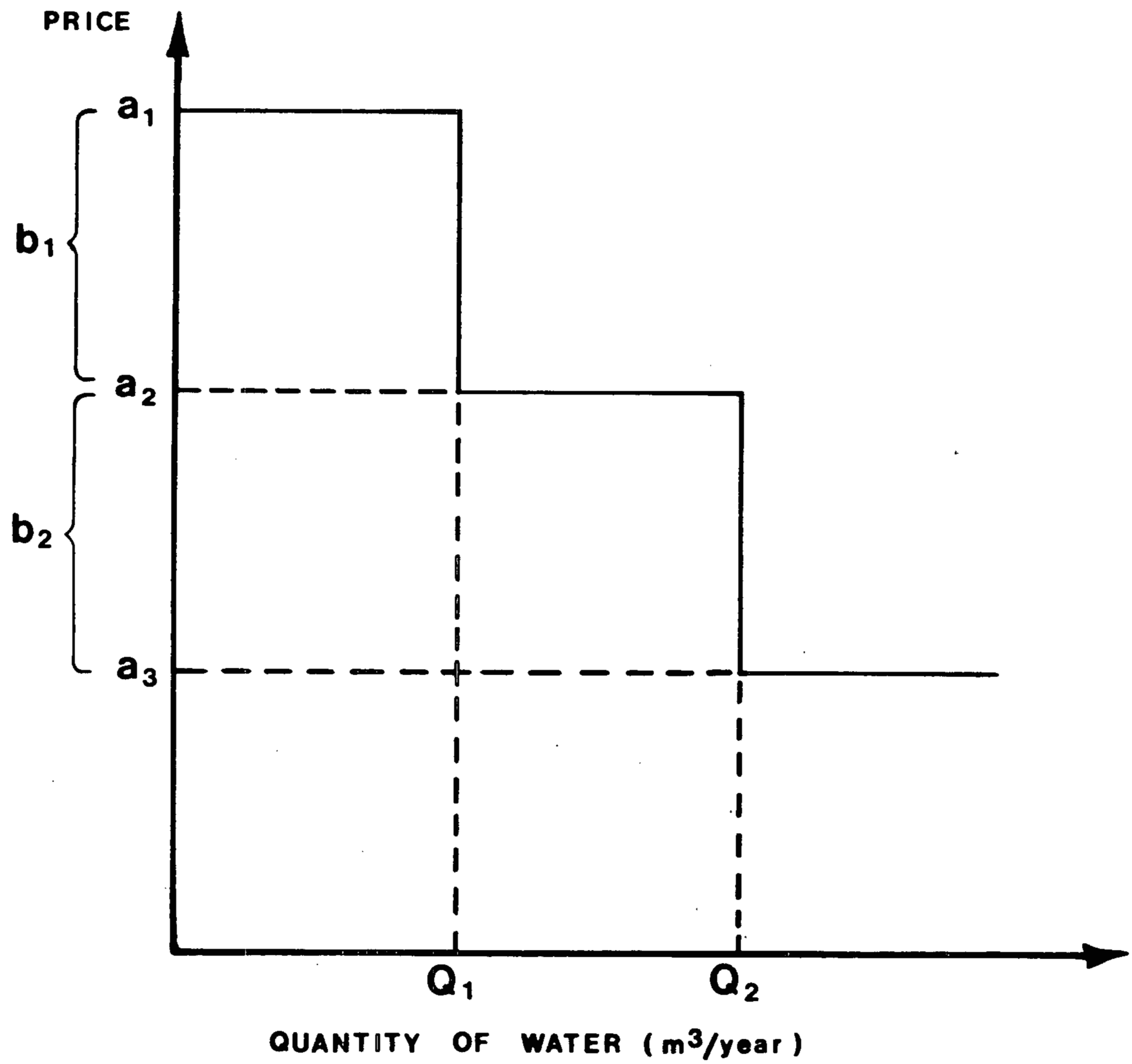
Specifically, the following equation will be estimated (using OLS techniques) in order to generate an instrumental estimate for the intake price of water:

$$(4)\quad P_i = \frac{TC_i}{Q_i} = \sum_j \beta_{ij} \bullet b_{ij} + \sum_j \alpha_{ij} \bullet d_{ij} + e_i$$

where P_i is the intake price, TC_i is the total cost of intake, Q_i is the quantity of intake water, all for the i^{th} firm. The set of regressors may be described through reference to figure 1. The b_{ij} are the differences between the levels of charges in the j^{th} block rate pricing structure facing the i^{th} firm. The d_{ij} regressors are a set of dummy variables. The first dummy tests for whether the firm is publicly or privately supplied. A second dummy tests whether the public utility is supplied from surface water or ground water. A final explanatory variable is included which measures the population of the town in which the firm is located. The last two variables are meant to capture any economies of scale in water

FIGURE 1

DECLINING BLOCK RATE
PRICE SCHEDULE



delivery affecting the nature of the block rate structure facing the firm[3].

The other price variable to receive special attention is the price of treatment prior to use. Because this variable is so closely related to the quality of the raw intake water it was decided to estimate an hedonic price function based on water treatment and to use this estimated function to generate the price of treatment proxy (rather than simply representing the price of treatment variable by the observed average cost of treatment)[4].

According to Rosen (1975) a two stage procedure is necessary in order to incorporate quality attributes into a demand model. First, the observed price is reqressed against the quality attributes:

$$(5)\ P(Z) = f\ (Z_1 \ldots Z_n)$$

where P(Z) is the observed price and the Z_i's are the quality attributes. Then the shadow price corresponding to each attribute is derived by taking the partial derivative of equation (5):

$$(6)\ P_i = \frac{\partial P(Z)}{\partial Z_i} = \frac{\partial f\ (Z_1 \ldots Z_n)}{\partial Z_i}$$

These shadow prices are then used as endogenous variables in the second-stage simultaneous estimation of the demand equations. An example of this procedure is found in Spady and Friedlaender (1978).

The procedure to incorporate quality considerations here is a

3 The procedure outlined should remove the simultaneity bias but may create a heteroscedasticity problem as the estimation of equation (7) draws observations from different block rate structures (cf. Jones and Morris, 1984, pp. 199-200).

4 In order to remain consistent this procedure should be followed for the price of treatment prior to discharge variable as well. Data limitations prevented this from being done.

simplified version of Rosen's method. The price of treatment prior to use (computed as the average cost) is regressed against the quantities of water receiving various types of treatment. The treatment variables included: chlorination, filtration, screening and hardness. The equation was estimated in double-log form:

$$(7)\ \ln (PTRT) = \sum_i a_i \ln (QT_i)$$

where the QT_i represent the quantity of water receiving one of the four treatment methods. The estimated equation was then used to generate the hedonic proxy for the price of treatment. It is hoped that this procedure will do two things. First, it will demonstrate the feasibility of incorporating the quality of water into an economic model of water use and second, it will indirectly act as an instrumental - variable type estimator (thus helping to reduce the simultaneity bias present in the estimation of the system of water use demand equations).

D. Conclusions

This chapter has detailed the econometric model and estimation procedures to be used in characterizing the water-use technologies of the four British Columbia manufacturing groups. A system of demand equations, derived from the non-homothetic Cobb-Douglas cost function, is to be estimated using a two stage iterative least squares procedure with the input prices of water intake, treatment prior to use, recirculation and treatment prior to discharge, and output as the arguments. The prices of recirculation and treatment prior to discharge are approximated by observed average cost. The prices of water intake and treatment prior to use are generated using instrumental variable and hedonic methods, respectively. Total employee hours serve as a proxy variable for output. The results of this project's empirical work are reported in the next chapter.

CHAPTER IV
EMPIRICAL RESULTS

A. Introduction

This chapter presents the results of the estimation procedures conducted for this project. In the next section the estimated coefficients of the water-use demand equations are reported and interpreted. The estimated instrumental variable and hedonic models are reported in an appendix.

B. Demand Equation Results

As indicated in the previous chapter the estimation model consisted of four demand equations: water intake, water treatment prior to use, water recirculation and water treatment prior to discharge. The explanatory variables present in each equation were the own price, the other three inputs' prices and the level of output. The equations were estimated simultaneously as a system with the homogeneity and cross-equation restrictions demanded by economic theory imposed. All equations were estimated in double-log form by a two-stage iterative least squares procedure on the computer econometric package SHAZAM (1978). The results from this estimation are reported in Table 4.1.

The first thing to be noted when interpreting the figures in Table 4.1 is that, because the estimated equations were in double-log form, the estimated coefficients may be interpreted as elasticities. Thus, the coefficient for ln(PIN) in the intake equation may be interpreted as the own price elasticity of intake water (equal to -0.118 for the Petro-Chemical industrial group), the coefficient for ln (PTRT) may be seen as the cross price elasticity of intake water with respect to the price of water treatment prior to use (in the case of Petro-Chemicals, equal to 0.058) and the coefficient on the ln (Q) term represents the output elasticity of intake water (equalling 1.63 for Petro-Chemicals). The coefficient

Table 4.1

Estimated Demand Equation Coefficients

Industry: Petro-Chemical

Demand Equations[1]

Variable[2]	Intake	Treatment	Recirculation	Discharge
Intercept	-8.2939 (-3.5368)	-26.351 (-6.8949)	-21.448 (-5.9757)	-9.0530 (-3.7653)
ln (PIN)	-0.11862 (-2.2625)	0.58297E-1 (0.46382)	0.14618 (2.1677)	-0.85849E-1 (-1.3203)
ln (PTRT)	0.58297E-1 (0.46382)	-0.36076 (-1.3459)	0.27856 (1.7846)	0.23901E-1 (0.19509)
ln (PRCR)	0.14618 (2.1697)	0.27856 (1.7846)	-0.59720 (-3.4366)	0.17246 (2.0795)
ln (POUT)	-0.85849E-1 (-1.3203)	0.23901E-1 (0.19509)	0.17246 (2.0795)	-0.11051 (-1.2760)
ln (Q)	1.6289 (7.8347)	2.6665 (7.7234)	2.4799 (7.9587)	1.6347 (7.7188)
	R^2=.6260	R^2=.6100	R^2=.6309	R^2=.5678

System LLF = -408.252
No. of Observations = 47

Table 4.1 (Cont'd)

Estimated Demand Equation Coefficients

Industry: Heavy

Demand Equations[1]

Variable[2]	Intake	Treatment	Recirculation	Discharge
Intercept	1.6620 (0.94282)	-8.6812 (-4.0723)	-3.9460 (-1.7188)	0.5001 (0.29723)
ln (PIN)	-0.24857 (-4.3412)	0.62342E-1 (1.2282)	0.25298 (5.0733)	-0.66754E-1 (-1.8456)
ln (PTRT)	0.62342E-1 (1.2282)	0.38777E-1 (0.5710)	-0.56161E-1 (-1.0608)	-0.44958E-1 (-1.0940)
ln (PRCR)	0.25298 (5.0733)	-0.56161E-1 (-1.0608)	-0.44526 (-5.6620)	0.25844 (5.2551)
ln (POUT)	-0.66754E-1 (-1.8456)	-0.44958E-1 (-1.0900)	0.25844 (5.2551)	-0.14673 (-3.5025)
ln (Q)	0.69397 (4.5978)	0.94915 (5.2292)	0.58836 (3.0290)	0.68698 (4.8097)
	R^2=.2289	R^2=.2890	R^2=.3320	R^2=.1922

System LLF = -819.025
No. of Observations = 91

Table 4.1 (Cont'd)

Estimated Demand Equation Coefficients

<u>Industry</u>: Forest

Demand Equations[1]

Variable[2]	Intake	Treatment	Recirculation	Discharge
Intercept	-3.1382 (-0.99336)	-18.971 (-4.5805)	-8.4194 (-2.3982)	-2.2838 (-0.79674)
ln (PIN)	-0.50599 (-8.8151)	0.49702 (7.6083)	0.15630 (5.0897)	-0.14733 (-4.7547)
ln (PTRT)	0.49702 (7.6083)	-0.92272 (-8.6393)	0.23266 (6.3604)	0.19303 (3.9620)
ln (PRCR)	0.15630 (5.0897)	0.23266 (6.3604)	-0.50891 (-9.4700)	0.11995 (4.4674)
ln (POUT)	-0.14733 (-4.7547)	0.19303 (3.6920)	0.11995 (4.4674)	-0.16566 (-4.8660)
ln (Q)	1.1659 (4.9498)	1.6647 (5.4067)	1.0514 (4.0255)	1.0450 (4.8994)
	R^2=.2392	R^2=.2139	R^2=.5442	R^2=.3000

System LLF = -946.828
No. of Observations = 104

Table 4.1 (Cont'd)

Estimated Demand Equation Coefficients

Industry: Light

Demand Equations[1]

Variable[2]	Intake	Treatment	Recirculation	Discharge
Intercept	-10.991 (-4.7689)	-5.6732 (-2.2540)	-8.9730 (-2.9514)	-7.5446 (-4.4290)
ln (PIN)	-0.53678 (-16.735)	0.50083 (15.069)	0.20889 (6.9514)	-0.17294 (-7.9774)
ln (PTRT)	0.50083 (15.069)	-1.0719 (-18.226)	0.38876 (9.4225)	0.18227 (5.9214)
ln (PRCR)	0.20889 (6.9036)	0.38876 (9.4225)	-0.77584 (-13.034)	0.17818 (6.0898)
ln (POUT)	-0.17294 (-7.9774)	0.18227 (5.9214)	0.17818 (6.0898)	-0.18751 (-7.4168)
ln (Q)	1.9439 (9.8356)	0.55238 (2.5622)	1.1837 (4.5802)	1.5514 (10.658)
	R^2=.2311	R^2=.6024	R^2=.4475	R^2=.3497

System LLF = -1071.83
No. of Observations = 130

Table 4.1 (Cont'd)

Estimated Demand Equation Coefficients

Notes:

[1]All equations were estimated in double-log form. The four equations were estimated as a system with homogeneity and cross equation restrictions imposed. The homogeneity restriction requires that the coefficients on the price terms sum to zero for each equation. The cross equation restrictions require that the matrix of price coefficients be symmetric. The figures in brackets are t values.

[2]The variable definitions are as follows:

ln (PIN) = log of intake price
ln (PTRT) = log of treatment of water prior to use price
ln (PRCR) = log of recirculation price
ln (POUT) = log of treatment prior to discharge price
ln (Q) = log of output

for ln(Q) measures the expected percentage growth in intake water demand when the company's level of output increases by one percent.

The demand equations appear to have relatively good explanatory power for all industries considering that the estimation is using cross-sectional data and is effectively averaging over possibly different technologies. Most of the coefficients are significant at the 0.05 percent level[1].

All of the own price terms have negative coefficients (with the exception of ln (PTRT) for the Heavy Industry group) and most are significant. Importantly, the own price terms for the price of water intake are negative and significant. The water intake price elasticities range from -0.12 for Petro-Chemicals to -0.54 for Light Industries. The relative magnitudes of these intake price elasticities conform to a priori expectations that as the water use cost share is greatest for Light Industries and this fact would suggest that Light Industries' water intake demands would be most price responsive. Similarly, Petro-Chemicals and Heavy Industries have quite low water cost shares and have correspondingly low intake price elasticities.

The pattern of cross-elasticity estimates across industries is quite revealing. It should be remembered that while the Cobb-Douglas form restricts all elasticities of substitution between inputs to equal one, cross-price elasticities can still be estimated. From Table 4.1 it can be seen that for all industries water intake and discharge are complements (as seen by the negative coefficient on the ln (POUT) variable in the intake demand equation) while water intake and treatment are substitutes. As well, water intake and recirculation are substitutes for all industries. This last observation certainly conforms to prior expectations.

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1 At the 0.05% level, the critical t values for 40 and 120 degrees of freedom, respectively, are 1.68 and 1.65 (Maddela, 1977, p. 507).

The intake water output elasticities are quite high with only the Heavy Industry group elasticity estimate being less than one. In particular, the estimates for the Petro-Chemical and Light Industry groups indicate that a one percent growth in output will lead to at least a one and one-half percent increase in water demands. However, for most industries (the Light Industry group being the exception) it should be noted that the intake output elasticity is quite close in magnitude to the discharge output elasticity. This would suggest that future growth in the manufacturing sector may lead to growth in water demands but not to substantial changes in water consumption rates for those industries. As well, it is encouraging to note that all industries (except the Heavy Industry group) have recirculation output elasticities greater than one. This would suggest that future industrial growth will, *ceteris paribus*, be characterized by increased use of recirculation.

C. Conclusions

The results presented here indicate that British Columbia manufacturing water demands are quite sensitive to economic variables such as the price of water and the prices of water treatment and recirculation. As well, the results suggest that increases in the price of water can be expected to lead to lowered water use and increased recirculation by industrial water users.

In the next chapter, the results of this project will be summarized and suggestions for future studies will be presented.

CHAPTER V

SUMMARY AND SUGGESTIONS FOR FUTURE STUDIES

A. Introduction

This chapter will summarize the methods used in the second phase of the British Columbia Industrial Water Demand project and will draw conclusions from the empirical results presented in the previous chapter. The final section of the chapter presents suggestions for future work.

B. Summary and Conclusions

The purpose of the second phase of this project was to extend and revise the results obtained during the first phase through the use of more sophisticated economic models and statistical techniques. With respect to the development of the economic model, the second phase based its estimation procedure on a system of water-use demand equations rather than single demand equations. The advantages of this development were that the alternative water uses (intake, recirculation, treatment prior to use and treatment prior to discharge) can be estimated simultaneously and that changes in the cost of one use may be modeled as affecting desired level of another use.

The statistical method employed to estimate the demand equations was also extended. In order to address the presence of simultaneity bias in the estimation procedure, an instrumental variable approach was adopted in the definition of the price of intake water. As well, attempts were made to incorporate considerations of water quality into the economic model and estimation procedure. This was done through the use of a hedonic price function to represent the price of water treatment prior to use.

The empirical estimates of the water-use demand equations were quite encouraging. The own price elasticities were consistently negative and output elasticities were consistently positive. A significant finding was that the Petro-Chemical and Heavy Industry groups had substantially less price responsive water intake demands than did the Light Industry group. On the other hand, all industry groups demonstrated intake-discharge complementarity and intake-recirculation substitutibility.

There are several conclusions which may be drawn from this project and its empirical results. Firstly, this type of study - an economic investigation into industrial water use - is feasible and is capable of explaining a substantial portion of the variations in industrial water use with relatively simple models and with easily acquired data. Second, an economic perspective can provide insight into water resource management problems. The possibility of using the price of water as an incentive to encourage conservation and the ability of firms to adopt recirculation as an alternative to increased intake are two topics which may be addressed using economic models. Third, the integration of water quality data into economic models of water demand is a feasible and potentially very important direction for water research. Finally, the output of this type of economic analysis could aid significantly in the planning and management of water resources. If planners are going to evaluate interbasin transfers of water or are going to determine the 'optimal' allocation of water within a basin, the relative valuation of water resources by users must be known. If conservation is to be encouraged, then the ability of users to substitute away from water use and the price responsiveness of water demands must be known. If water demands are to be forecast then the structure of water use technology and the effects on water use of changes in prices must be known. The type of economic analysis conducted in this project can contribute to all of these policy related questions.

C. <u>Suggestions for Future Studies</u>

Very little is known about the economic nature of water use in

Canada. This situation must change if Canada is to derive maximum benefits from its use of water resources. In the following section suggestions are made for future economic studies of water resources in Canada.

1. <u>Economic Analysis of Water Quality</u>

   More attention should be paid to incorporating water quality considerations into water demand models for all sectors. As well, building water quality considerations into river basin optimization studies and into forecasting models should be attempted. These types of efforts could lead to further studies which examine the costs and benefits of changing water quality.

2. <u>Water Demand Modeling</u>

   The study has examined the British Columbia manufacturing sector's water demands. Future studies could extend these results by considering other sectors or by studying the entire Canadian manufacturing sector or by using a less aggregated data set. As well, more sophisticated economic models and econometric techniques are available. Specifically, the demand for water should be modeled as one of a system of interrelated input demands including non-water inputs such as labour, capital and energy inputs. Once the 1986 Industrial Water Use Survey is completed a pooled time series cross sectional data set could be constructed and used to study both short run and long run substitution possibilities between water and other inputs. Finally the models of water demands which are developed could ultimately be integrated into the existing large macro economic computer models of the Canadian economy.

   Another stream of research which could flow from the basic water demand modeling concerns the valuation of water. Water demand functions could be translated into water valuation functions.

These could be applied to optimal allocation projects in which net benefits from water use would be maximized through the allocation of water to its highest valuers. Ultimately research into optimal water pricing and the design of quasi-markets for water could lead to the use of auctions in which competing users could bid for the right to secure supplies of water.

3. <u>Data Gathering</u>

An increased data gathering effort is certainly a prerequisite to an expanded economic research effort. Much of the basic information regarding municipal and commercial water use has never been collected. Industrial water use has only limited coverage by the series of Industrial Water Use Surveys. Perhaps this type of data gathering could be extended to other sectors such as domestic and farming water use.

In addition to collecting more economic data concerning water use an effort should be made to integrate the collection of economic data with the collection of information concerning water quality and other physical characteristics of water. This integration will certainly be necessary if water quality is ever to receive substantial economic analysis.

APPENDIX

The purpose of this appendix is to document the estimated forms of the instrumental variable and hedonic price functions. The economic basis for the construction of these functions is discussed in Chapter Two. A description of the estimated equation forms is in Chapter Three.

Instrumental Variable Equation

The following equation was estimated using the entire British Columbia data set. Once estimated, it was used to generate intake prices for each of the four industry groups. The estimated equation is the following:

$$(LAC) = \underset{(-3.28)}{-2.4147} + \underset{(4.73)}{0.088088}\,(LD1) - \underset{(-2.91)}{0.061774}\,(LD2) - \underset{(-2.44)}{2.0811}\,(DR)$$

$$\underset{(-4.82)}{-2.1729}(DB) + \underset{(0.35)}{0.023149}(LPOP) + \underset{(1.38)}{0.59595}(D6)$$

DF = 158 F = 100.174 R^2=.3349
(the figures in brackets are t values)

where:

LAC = log of average cost of intake
LD1 = log of difference in prices between blocks one and two
LD2 = log of difference in prices between blocks two and three
DR = dummy variable, = 1 if privately supplied
= 0 otherwise
DB = dummy variable, = 1 if privately and publically supplied
= 0 otherwise
LPOP= log of population served by the public utility supplying the respondent firm.
DG = dummy variable, = 1 if utility supplying respondent draws from ground water
= 0 otherwise

Hedonic Price Functions

One hedonic price function was estimated for each of the four industry groups. These equations related the average cost of water treatment prior to use to the quantities of water receiving various types of water treatment. The equation results are summarized in the following table.

Table A.1

Estimated Hedonic Price Functions

Variable	Industry PetroChemical	Heavy	Forest	Light
Constant	-0.28792 (-0.15)	-3.0619 (-1.40)	-3.2786 (-2.02)	-0.78762 (-0.87)
LQF	-0.67594E-2 (-0.45)	-0.31231 (-1.23)	-0.80826E-1 (-6.85)	-0.34092 (-3.94)
LQC	-0.37120 (-3.04)	-0.18913 (-0.94)	-0.16404 (-1.16)	-0.19537 (-2.42)
LQS	-0.27727 (-2.46)	-0.37345 (-1.86)	-0.26692 (-2.49)	-0.46583 (-3.32)
LQH	-0.66729E-1 (-1.53)	-0.23139 (-7.87)	0.67475E-1 (-0.53)	-0.76534E-1 (-0.75)
R^2	.3569	.1161	.0814	.4299
F	19.736	9.919	13.210	28.663

Where:

LQF = log of quantity of water filtered
LQC = log of quantity of water chlorinated
LQS = log of quantity of water screened
LQH = log of quantity of water treated for hardness

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