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How “natural” are natural monopolies in the water supply and sewerage sector?

Case studies from developing and transition economies*

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Abstract

We estimate measures of density and scale economies in the water industry in Brazil, Colombia, Moldova and Vietnam, four countries that differ substantially in economic development, piped water and sewerage coverage and characteristics of the utilities. We find evidence of economies of scale in Colombia, Moldova and Vietnam. In Brazil, we cannot reject the null hypothesis of constant returns to scale. The results of this study show that the cost structure of the water and wastewater sector varies significantly between countries and within countries, and over time, which has implications for how to regulate the sector.

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1. Introduction

The provision of piped water and sanitation services is often cited as the typical textbook illustration of a natural monopoly. This "natural monopoly" concept reflects technological and associated cost attributes that imply that a single firm can produce at a lower cost than multiple firms (Joskow, 2005). Such natural monopolies arise where the largest supplier in an industry, or the first supplier in a local area, has an overwhelming cost advantage. This tends to be the case in industries where capital costs are large and as a result create barriers to entry. The existence of a natural monopoly is one of the main reasons for regulating the sector. Yet, so far there have been few analyses of the cost structure of water utilities in particular in developing countries.

Overall, studies of the performance of water utilities in developed countries provide contrasting findings regarding scale economies in this sector. Using data on 190 public and 31 private urban water utilities from the United States, Bhattachryya et al. (1995) estimate returns to density at the mean (the short-run equivalent of returns to scale) at 1.25 for privately owned utilities and at 0.93 for publicly owned utilities; they find economies of scale for only private water utilities. Kim and Lee (1998), using data for 42 Korean municipal water supply companies for the period between 1989 and 1995, find evidence of diseconomies of scale in four cities, constant returns to scale in 12 cities, and economies of scale in 12 cities. Fabbri and Fraquelli (2000), using data on Italian water utilities, cannot reject constant returns to scale at the mean. Saal and Parker (2000), using data on water and sewerage companies from England and Wales, report diseconomies of scale at the mean (see also Hunt and Lynk, 1995, for a study of the UK water industry). Garcia and Thomas (2001), using a panel of French local communities, cannot reject the hypothesis of constant returns to scale (for the delivery of water supply services). They even find evidence of diseconomies of scale for some utilities, in particular utilities which deliver a high volume of water per customer. Mizutani and Urakami (2001) also find evidence of slight diseconomies of scale at the mean for Japanese water utilities.

As far as water utilities in developing and transition economies are concerned, the main focus has been on efficiency measures computed through the estimation of a stochastic cost frontier or using the Data Envelopment Analysis (DEA) technique (see Estache, Perelman and

Trujillo, 2005, for a survey). Estimates of cost functions and returns to scale are very scarce; we found only one study that calculated returns to scale from a DEA study.[2] The current paper contributes to fill this gap by deriving measures of density and scale economies from the estimation of a Translog cost function using panel data from IBNET on water and sewerage utilities in four countries that differ substantially in economic development: Brazil, Colombia, Moldova, and Vietnam.[3]

Because of high collinearity between the volume of water supplied and the volume of wastewater treated for utilities providing both water and sewerage services, we estimate a single product Translog cost function for all four countries. In this case economies of scale are a sufficient condition for natural monopoly (Joskow, 2005). We find evidence of economies of scale in Colombia, Moldova and Vietnam, implying the existence of natural monopoly. In Brazil, we cannot reject the null hypothesis of constant returns to scale, which is inconclusive in terms of natural monopoly characteristics. We also find evidence of economies of customer density in Moldova and Vietnam: additional water users could be connected to the piped water network at decreasing average cost. We discuss the policy implications of these results in significant detail.

This study provides new insights about the cost structure of water utilities in lower- and middle-income countries. Understanding the size of economies of scale in the water supply and sewerage industry helps to ensure that firms and policymakers can make informed decisions. If there are economies of scale and growing demand, firms may find it profitable to add more capacity than they expect to use in the immediate future. Furthermore, if there are economies of scale over the domain of market demand, large firms could produce at lower average costs than smaller ones; thus a competitive equilibrium would not be sustainable and a valid policy argument can be made for the establishment of a large firm (or monopoly) in order to gain the benefits of these economies (Kim, 1987).

We define the concepts of cost function, economies of density and scale, and natural monopoly in section 2. The specification of the cost function that is estimated for each of the

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[2] The one study we found was conducted by Seroa da Motta and Moreira (2006) who compute returns to scale from a DEA approach using data from Brazil. Findings from this study will be discussed later.

[3] The International Benchmarking Network (IBNET) is developed by the World Bank with the objective to improve the service delivery of water supply and sewerage utilities through the provision of international comparative benchmark performance information. For more information, see www.ib-net.org

four countries is discussed in section 3. In the next section, we present data and background information, while in section 5 we comment on the estimation results. We conclude with a discussion on the policy implications of our results.

2. Cost function, economies of density and scale, natural monopoly

The analysis of the cost structure of water utilities will be based on the estimation of the associated cost function. The water utility is assumed to make its input decisions in order to minimize the cost of producing some output level. The water utility's total cost can be represented by

$$C = C\left(y, w, z, t, f\right) \tag{1}$$

where y is the vector of outputs produced by the utility, w is the vector of input prices, z is a vector of control variables, t are time-specific shifts, and f are utility-specific shifts. The set of outputs to be selected depends on the activities of the utilities and on the availability of data. In what follows, we propose a general description of the cost function for a representative utility providing water supply and sewerage services. We consider two outputs: the total volume of water produced by the water utility (y_{ws}) and the total volume of wastewater treated (y_{ww}).[4]

The major production factors for water and sewerage utilities are labor, energy, and capital. The underlying assumption is that the utility manager minimizes the cost with respect to all inputs, which implies that the level of all factors can be instantaneously adjusted. This is not a realistic assumption for capital stock though, which is generally considered a quasi-fixed input. For that reason, it is common to estimate a variable cost function or short-run cost function, in which capital is assumed to be fixed. The variable cost function includes prices of variable inputs and the stock of capital enters as a control variable (Caves, Christensen, and Swanson, 1981). We will follow this approach here and, from now on, C will stand for total variable cost incurred by the utility. In the subsequent empirical application, the variable inputs that are considered in the cost function are the costs of contracted out services (which gather costs of all services provided by third firms), energy cost, labor cost, and miscellaneous (or other) costs. The set of corresponding input prices will thus be $w = \left(w_c, w_e, w_l, w_o\right)$. Capital stock will be proxied by length of the water distribution network (*len*).

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[4] Generalization of the cost function to the *k*-output case (k>2) would be easy.

Because utilities may operate in different environments and the quality of the service that is provided to customers may vary across utilities, we need to include control variables in the cost function.[5] These control variables can include: *dur,* the average duration of water supply services (in hours per day); *eff*, efficiency as measured by the ratio of total volume sold over total volume produced; *mco,* the percentage of metered connections; *ntow*, the number of towns served by the water utility; *pbr,* the number of pipe breaks that occurred on the distribution network in a given year; *pop,* the total population served by the water utility; and *vres*, the proportion of the volume of water sold to residential customers.

The estimation of a cost function as defined in (1) allows to compute various measures of economies of density and scale.

Economies of production density

We examine how the cost of the utility is changing if the total volume of water produced and the total volume of treated wastewater are increased, holding the number of customers (*pop*) and network length (*len*) constant. The elasticity of cost with respect to water produced and treated wastewater is defined as:

$$\varepsilon_{W} = \frac{\partial \ln C}{\partial \ln y_{ws}} + \frac{\partial \ln C}{\partial \ln y_{ww}} \text{ (Panzar and Willig, 1977),}$$

and returns to production density are measured by:

$$R_{pd} = \frac{1}{\varepsilon_{W}}.$$

If R_{pd} is greater than 1, economies of production density exist; if R_{pd} is equal to 1, then constant returns to production density exist; and when R_{pd} is smaller than 1, we have diseconomies of production density.

Economies of customer density

A second measure that can be derived is economies of customer density. It measures how cost changes if total water produced, total volume of treated wastewater and the number of customers increase, under the assumption that the network length is constant. The effect of adding new customers on cost is computed by:

$$\varepsilon_{pop} = \frac{\partial \ln C}{\partial \ln pop}.$$

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[5] See Mocan (1995) and Saal and Parker (2000) for a discussion of quality-adjusted cost functions.

Economies of customer density exist if

$R_{cd} = \dfrac{1}{\varepsilon_w + \varepsilon_{pop}} > 1$ with R_{cd} the returns to customer density.

The measurement of economies of customer density is important for developing countries where still large numbers of households do not have access to safe water supplies and sanitation services. If there is evidence for economies of customer density then new connections can be added at a decreasing average cost.

Economies of scale

We measure economies of scale by considering the change in cost following a change in volume of water produced and volume of wastewater treated, number of customers to be served, and network length. If we define the elasticity of cost with respect to network length by

$$\varepsilon_n = \frac{\partial \ln C}{\partial \ln len},$$

then returns to scale are measured by

$RTS = \dfrac{1-\varepsilon_n}{\varepsilon_w + \varepsilon_{pop}}$, see Caves, Christensen, and Swanson (1981).

Economies of scale exist when $RTS > 1$; if $RTS = 1$, the industry exhibits constant returns to scale; and if $RTS < 1$, diseconomies of scale occurs. In an industry experiencing economies of scale, the marginal cost of producing a service decreases as production increases. Similarly, $RTS > 1$, $RTS = 1$, $RTS < 1$ as the revenues from pricing services at marginal cost falls short of, equal or exceed the cost of production.[6]

Note that returns to scale can be seen as the long-run counterpart of returns to density, which measure the response of cost-minimizing output to a constant percentage change in all variable inputs, holding the variable input prices and the amount of the quasi-fixed factor constant (Caves et al., 1984).

Natural monopoly

We follow the technological definition of the natural monopoly proposed by Joskow (2005). In the single product case: "*a firm producing a single homogeneous product is a natural*

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[6] Consequently, a firm with economies of scale cannot recover its costs with marginal cost pricing.

monopoly when it is less costly to produce any level of output of this product within a single firm than with two or more firms". This definition corresponds to the property of subadditivity of the cost function (Sharkey, 1982), which (in the single product case) is equivalent to economies of scale. Consequently, in the single product case, economies of scale are a sufficient but not necessary condition for natural monopoly (Joskow, 2005).

The conditions for a natural monopoly in the multi-product case are quite complex and will not be detailed here since the empirical application is made in the single product context.[7] Interested readers should refer to Sharkey (1982).

It is important to keep in mind that natural monopoly characteristics according to the above technological definition (i.e. subadditivity of the cost function) does not by definition imply market or monopoly power. The latter has to do with the existence of close substitutes and the geographic area supplied by the firm. Hence, even if an industry has natural monopoly characteristics, it does not by definition implies that the industry has monopoly power.

3. Specification of the cost function

We choose the Translog functional form (see Christensen, Jorgenson, and Lau, 1973) which has been widely used in cost studies. The Translog is a flexible form in the sense of providing a second-order approximation to any unknown cost function.

The generalized Translog cost function for a representative water utility, including time- and utility-specific effects, has the following form:[8]

$$\begin{aligned}\ln(C_t) &= \alpha_0 + \alpha_f + \sum_t \alpha_t + \sum_{i=ws,ww} \beta_i \ln y_{it} + \sum_{j=c,e,l,o} \lambda_j \ln w_{jt} + \sum_{\substack{r=len,dur,eff,mco,\\ ntow,pbr,pop,vres}} \gamma_r \ln z_{rt} \\ &+ \frac{1}{2}\sum_i \sum_k \beta_{ik} \ln y_{it} \ln y_{kt} + \frac{1}{2}\sum_j \sum_m \lambda_{jm} \ln w_{jt} \ln w_{mt} + \frac{1}{2}\sum_r \sum_s \gamma_{rs} \ln z_{rt} \ln z_{st} \qquad (2) \\ &+ \sum_i \sum_j \rho_{ij} \ln y_{it} \ln w_{jt} + \sum_i \sum_r \kappa_{ir} \ln y_{it} \ln z_{rt} + \sum_j \sum_r \eta_{jr} \ln w_{jt} \ln z_{rt},\end{aligned}$$

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[7] This is also the reason why we do not discuss, in this section, the concept of *economies of scope*, which is relevant in the multi-product case only. *Economies of scope* exist if the same firm can produce several commodities at a lower cost than would firms specialized in each product.

[8] The utility index is not shown in order to avoid extra indices.

where $\beta_{ik} = \beta_{ki}$, $\lambda_{jm} = \lambda_{mj}$, and $\gamma_{rs} = \gamma_{sr}$. C_t represents total variable costs in year t, α_0 is the constant term, the α_t's are year-specific effects, and α_f is the utility-specific effect. Theory requires that the cost function must be homogeneous of degree one in input prices, which is typically satisfied by dividing variable cost and input prices by the price of one input (we choose the price of labor). The homogeneity property implies the following restrictions on the parameters of the Translog cost function:

$$\sum_j \lambda_j = 1,\ \sum_j \lambda_{jm} = \sum_m \lambda_{mj} = 0,\ \sum_j \rho_{ij} = \sum_j \eta_{jr} = 0.$$

The theory of cost and production also requires that the own-price elasticities of the variable inputs be negative and that the Hessian matrix, $\left[\partial^2 C / \partial w_j \partial w_m\right]$, be negative semidefinite. We will check that these properties are satisfied on our data at the estimation stage.

Given the large number of parameters to be estimated in (2), it is better to make use of the cost share equations implied by Shephard's (1953) lemma:

$$\frac{w_{jt} x_{jt}}{C_t} = S_{jt} = \frac{\partial \ln C_t}{\partial \ln w_{jt}} = \lambda_j + \sum_m \lambda_{jm} \ln w_{mt} + \sum_i \rho_{ij} \ln y_{it} + \sum_r \eta_{jr} \ln z_{rt} \tag{3}$$

for $j = c,e,l,o$, where x_{jt} represents derived demand of input j in year t.

Own-price elasticities, which measure the variation in input demand following a change of its price, are obtained as $\varepsilon_{jj} = \gamma_{jj} / S_j + \left(S_j - 1\right)$, and cross-price elasticities are computed as $\varepsilon_{jm} = \gamma_{jm} / S_j + S_m$, $\left(j \neq m\right)$. Morishima elasticities of substitution are defined as $\sigma_{jm} = \varepsilon_{jm} - \varepsilon_{mm}$. Morishima elasticities measure the ease of substitution between factors j and m, and constitute a sufficient statistic for assessing the effects of changes in input price ratios on relative factor shares (Blackorby and Russel, 1989).[9]

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[9] Hicks (1932) was the first to introduce and discuss a dimensionless measure of substitutability of the input factors, the so-called elasticity of substitution, for a two-factor production. The Hicks elasticity of substitution is defined as the relative change in the proportion of the two input factors as a function of the relative change of the corresponding marginal rate of technical substitution. With more than two input factors, Blackorby and Russel (1989) showed that the Morishima elasticity of substitution preserves the properties of the original Hicks measure.

4. Data and background information

Data for the four selected countries (Brazil, Colombia, Moldova, and Vietnam) have been taken from the International Benchmarking Network (IBNET). These four countries differ in many respects, in particular regarding their level of economic and social development.

Brazil has a diversified middle-income economy with wide variations in levels of economic development across the country. After decades of inflation, Brazil embarked on a successful economic stabilization program, the Real Plan in July 1994. Inflation, which had reached an annual level of nearly 5,000 percent at the end of 1993, fell sharply, reaching 8 percent in 2004. In 2004, Gross National Income (GNI) was US$3,000 per capita (see table 1).[10]

After experiencing decades of steady growth (average GDP growth exceeded 4 percent in the 1970-1998 period), Colombia entered into a recession in 1999, and the recovery from that recession was long and painful. Colombia's economy suffers from weak domestic and foreign demand, austere government budgets, and serious internal armed conflicts. Inflation was moderate in the last few years (about 7 percent in 2004). In 2004, GNI reached US$2,020 per capita (table 1).

Although the Moldovan economy experienced a constant economic growth after 2000 it still ranks low in terms of commonly-used living standards and human development indicators in comparison with other transition economies. Moldova remains the poorest country in Europe in terms of GDP per capita. In 2004, the registered GNI per capita was US$720 (table 1). An estimated 40 percent of population lives under the absolute poverty line.

In 1986, the Sixth Party Congress of the Communist Party of Vietnam formally began introducing market elements as part of a broad economic reform package. Vietnam achieved around 8 percent annual GDP growth from 1990 to 1997 and continued at around 7 percent from 2000 to 2002, making it the world's second-fastest growing economy. Vietnam, however, is still a poor country with GNI of US$380 per capita in 2000, reaching US$540 per capita in 2004.

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[10] *Gross National Income or GNI (formerly GNP), current dollars* is the sum of value added by all resident producers plus any product taxes (less subsidies) not included in the valuation of output plus net receipts of primary income (compensation of employees and property income) from abroad. Source: World Bank.

The Brazilian National Sector Information System (SNIS) which is a partner in the International Benchmarking Network (IBNET) provides annual information on 27 Brazilian regional water utilities for the period between 1996 and 2004. All surveyed water utilities but one provide water and sewerage services.[11] In Colombia, 228 utilities have been surveyed in 2003 and 2004, but because of missing information for some variables of interest, only 48 utilities can be used at the estimation stage. These 48 utilities provide both water and sewerage services.[12] In Moldova, performance data are available for 41 water and sewerage utilities for each year between 1996 and 2004. Moldovan water utilities provide water and sewerage services, except for two utilities which provide only water services and one utility which stopped providing water services after 2002. For Vietnam, information on 67 provincial water utilities offering only water supply services is available for the period covering the years from 1997 till 2000.[13]

Because the sub-sample of utilities providing only water services in Brazil and in Moldova is very small (1 out of 27, and 2 out of 41, respectively), we restrict the analysis to the respectively 26 utilities in Brazil and 39 utilities in Moldova which provide both water and sewerage services. In these two countries and in Colombia, the provision of both water and sewerage services should call for the estimation of a two-output cost function, i.e., the total volume of water produced and the total volume of wastewater collected and treated. However, for the three countries, the coefficient of the wastewater volume was not found significant in the cost function (which would mean that an increase in the amount of wastewater collected and treated does not significantly increase the variable cost of the utility). We believe that the non-significance of this parameter is driven by the high collinearity between the two output variables. High collinearity was also observed for control variables such as network length (water supply network length is highly collinear with sewerage network length), and population to be served (population supplied with water is almost perfectly collinear with population connected to the sewerage system). For that reason, and because estimates of

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[11] See Tupper and Resende (2004) and Seroa da Motta and Moreira (2006) for a description of the institutional and regulatory background of the Brazilian water and sewerage sector.

[12] Note that we cannot check if the final sample gathering 48 utilities is representative since information on the water utility size (volume of water produced and number of served customers) is missing for 129 utilities.

[13] The original dataset contains data up to 2003. However, because of inconsistency in the data from 2001 onwards, we decided to consider only the 1997-2000 period in the econometric analysis.

density and scale economies were almost unchanged, we consider the total volume of water produced as the single output in the cost function, i.e., we have $y = \{y_{ws}\}$.[14,15]

The set of available input prices and control variables varies from one country to the other (see table A1 in Appendix). When available, we consider four inputs: costs of contracted out services, energy, labor, and miscellaneous costs (the latter is defined as the difference between total operational expenses and the sum of contracted out services costs, energy, and labor costs). The labor input is measured by the total number of staff working at the utility (reported in terms of Full Time Equivalent (FTE) staff numbers), and the unit labor price is obtained by dividing labor costs (including salaries, wages, pensions) by FTE staff numbers. For contracted out services, energy, and miscellaneous inputs, we build three price indices by dividing the corresponding total costs by total volume produced.[16]

The set of control variables includes: *len*, the length of the water distribution network; *dur,* the average duration of supply (in hours per day); *eff*, efficiency as measured by the ratio of total volume sold over total volume produced; *mco,* the percentage of metered connections; *ntow*, the number of towns served by the water utility; *pbr,* the number of pipe breaks that occurred on the distribution network; *pop,* the total population served by the water utility; and *vres*, the proportion of volume of water sold to residential customers. Unfortunately, information on water quality delivered by the water utilities is not available in any of the four countries. In each country, all monetary amounts have been converted into constant terms using the GDP deflator provided by the World Bank (see table 1). In all cases, the base year is the first year of the study period.[17]

We present some descriptive statistics of our data for each country in table 2. The average size of the utilities varies substantially across the four countries. In Moldova, the average water supply and sewerage (WSS) utility produces 4 million cubic meters per year, and distributes water to 30,000 persons through a 90km-network.[18] In Vietnam, the average water utility

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[14] As far as we know, Saal and Parker (2000) are the only authors to consider water supply and sewerage as two distinct products when estimating the cost function of water utilities, that they measure respectively with the residential population supplied with (drinking) water and the population connected to sewerage treatment works.

[15] The estimation of a single-product cost function rules out the possibility of measuring economies of scope.

[16] See also Garcia and Thomas (2001) for similar procedure.

[17] The base year is 1996 for Brazil and Moldova, 1997 for Vietnam, and 2003 for Colombia.

[18] From now on, utilities that provide both water supply and sewerage services will be called 'WSS utilities', while utilities providing only water services will be called 'water utilities'.

produces 13 million cubic meters per year for a population of 142,000 through a network of 166 kilometres. In Colombia, the average WSS utility produces 22 million cubic meters and serves 229,000 persons (network length is 322 km on average). Finally, regional WSS companies in Brazil produce on average 390 million cubic meters per year, serve 3,784,000 persons through a network length of 10,715 km.

Population coverage (i.e., the share of the total population of the area under utility's responsibility which is supplied by the utility) is 49 percent in Vietnam, 63 percent in Moldova, 88 percent in Brazil, and reaches 95 percent in Colombia. The lowest density of customers is observed in Moldova (on average 275 customers per kilometre of network). Density of customers is slightly higher in Brazil (on average 376 customers per kilometre of network) and reaches 664 and 788 customers per kilometre of distribution network in Colombia and Vietnam, respectively. Energy costs represent about one-third of total operational expenses in Colombia, Moldova, and Vietnam, while it is much lower in Brazil (11 percent). Labor costs represent between 31 percent (in Vietnam) and 40 percent (in Brazil) of total operational expenses in the four countries.

5. Estimation results

Because the economic and regulatory environments in which utilities operate can be very different from one country to the other, we estimate the system combining the Translog cost function and the cost share equations separately for the four countries.

For Brazil, Moldova, and Vietnam, we specify time-specific and utility-specific unobservable effects. Utility-specific effects, which capture all unobservable time-constant utility characteristics (e.g., efficiency of the utility manager), cannot be considered when estimating the model on the Colombian data because utilities have been surveyed only twice. We estimate the Translog cost function along with the input cost share equations using Zellner's (1962) technique for estimation of a system of seemingly unrelated equations, under the assumption of fixed utility- and time-specific effects.[19] To overcome the problem of singularity of the covariance matrix, we delete one of the share equations. The regressors are all normalized by removing their sample mean. This mean-scaling transformation, which is

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[19] The system has been estimated using the (iterated) SUREG procedure from STATA software.

commonly performed when estimating Translog cost functions, amounts to choosing the mean as the reference point for local approximation.

The set of control variables selected as extra explanatory factors in the cost function varies from one country to the other. In all cases, we keep the set of variables which yields the best fit to the data. Finally, the Translog cost function is estimated using data from 26 WSS utilities in Brazil (a total of 213 observations), 48 WSS utilities in Colombia (a total of 78 observations), 38 WSS utilities in Moldova (a total of 237 observations), and 49 water utilities in Vietnam (a total of 145 observations). Estimated parameters of the four Translog cost functions (except for the utility-specific effects) are shown in Appendix (tables A2, A3, A4, and A5, for Brazil, Colombia, Moldova, and Vietnam, respectively).

The goodness of fit of the Translog cost model is around 0.99 in the four models. The good fit of the model to the data is also reflected in the test of regulatory properties of the cost function. A well-behaved cost function should be: (i) monotonically increasing in input prices, (ii) monotonically increasing in output, and (iii) concave in input prices. In the case of a Translog cost function, conditions (i) and (ii) are satisfied if the estimated factor shares, $\hat{S}_{jt}$ ($j=c,e,l,o$), and the estimated elasticity of cost with respect to output are positive at all data points. A necessary and sufficient condition for a twice continuously differentiable cost function to be concave in input prices requires negative semi-definiteness of the matrix of second-order partial derivatives of the cost function with respect to input prices. We check that these properties are satisfied on our data.

Cost elasticities

Since variable cost and the regressors are in natural logarithms and have been normalized (mean-scaling), the first-order coefficients are all interpretable as cost elasticities evaluated at the sample mean (see table 3).[20]

The coefficients of the output variable and the input prices have the expected signs and are highly significant in the four countries. As one would expect, there is a strong positive relationship between total variable cost and output when all other factors are fixed. A one percent increase in volume of water produced leads to an increase in total variable cost which

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[20] By sample mean, we mean the service with the average characteristics in each country.

varies from 0.61 percent in Vietnam to 0.96 percent in Moldova. The lowest cost elasticity is estimated for Vietnam which is the only country where utilities only provide water services.[21]

The elasticities of cost with respect to the factor prices are equivalent to shares in total cost. Thus, at the sample mean, energy accounts for approximately 32 percent of utility variable costs in Colombia and Vietnam, 38 percent in Moldova, but only 11 percent in Brazil. The control variables are, overall, less significant in the four models. We find that length of distribution network has a significant impact on variable costs in Brazil and in Vietnam (elasticity is small, estimated at around 0.1 and 0.06, respectively). A larger population served by the water utility is found to increase variable costs in Brazil, Colombia, and Vietnam. A one percent increase in the number of supplied customers results in an increase in variable costs by 0.1 percent, 0.2 percent, and 0.3 percent, respectively. Maybe surprisingly, the variable measuring duration of water supply (average number of hours per day) has a negative and significant effect on total variable cost in Vietnam (cost elasticity is estimated at –0.18). In Colombia, variable costs are found to decrease when the proportion of total volume sold to residential consumers increase, possibly suggesting that non-residential consumers tend to be more expensive to serve. The lower non-revenue water (as measured by a lower ratio of water sold versus water produced), the lower the total variable cost. Reducing non-revenue water has a positive impact on the total variable costs, but is only significant at the 10 percent level, and not significant in the case of Brazil. Finally, we do not find any significant impact of the number of pipe breaks and of the share of metered connections on the total variable cost, at the sample mean.

Own-price elasticities and Morishima elasticities of substitution

Own-price elasticities and Morishima elasticities of substitution are shown in table 4. In all cases, standard errors have been computed using Kmenta (1986)'s method. All own-price elasticities are negative and significant, indicating that the demand of any input decreases when its price increases. The four inputs are found quite inelastic to their own prices in the four countries. The elasticity of energy demand to its own price varies from -0.13 in Colombia to –0.26 in Vietnam (i.e., a 1 percent increase in energy price decreases the demand for energy inputs by 0.13 percent and 0.26 percent respectively). For labor, elasticity varies from

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[21] This comment refers to the concept of *economies of scope* that we cannot measure here since collinearity in the data did not permit the estimation of a two-product cost function.

–0.10 in Brazil to –0.30 in Vietnam. Morishima elasticities of substitution are all found positive, indicating that the four inputs are substitutes, in the four countries.

Returns to density and returns to scale

We present estimates of returns to production density (R_{pd}), returns to customer density (R_{cd}), and returns to scale (*RTS*), computed at the sample mean, in table 5. In all cases, we report the estimated standard error and we test the null hypothesis that the estimated return is constant (H0: estimated return = 1); again the alternative is that the estimated return is increasing or decreasing (H1: estimated return < 1 or estimated return > 1). We find significant increasing returns to density in the four countries. Note that, because we consider a single-output cost function, economies of production density are computed as:

$$R_{pd} = \frac{1}{\varepsilon_w} \text{ with } \varepsilon_w = \frac{\partial \ln C}{\partial \ln y_{ws}} .$$

In all four countries, an increase in the total volume of water produced, while holding the length of the network and the number of customers constant (i.e., an increase in water consumption per customer), would decrease average variable costs. Estimated returns to production density varies from 1.39 in Brazil to 1.69 in Colombia, thus showing that the water industry, in the four countries, exhibit significant economies of production density.

We find significant economies of customer density in Moldova and Vietnam but we cannot reject the hypothesis of constant returns to customer density in Brazil and Colombia. In other words, an increase in the total volume of water produced along with an increase in the number of supplied customers (while holding the network length constant) is found to decrease average variable costs only in Moldova and Vietnam. Constant returns to customer density in Brazil and Colombia may be explained by the relatively high access to piped water in these countries (86 percent and 95 percent, respectively, see table 2).

Returns to scale, which can be seen as the long-run counterpart of returns to production density, are found to be increasing in Colombia (estimated at 1.11), Moldova (1.26) and Vietnam (1.16). In Brazil, we cannot reject the null hypothesis that returns to scale are constant, at the sample mean. Put differently, the water and sewerage industry is found to be characterized by economies of scale (or has natural monopoly characteristics) in Colombia, Moldova, and Vietnam.[22] Estimated returns at the sample mean for the four countries lie in the range of returns to scale estimated in developed countries (see Mizutani and Urakami, 2001, for a review). For the case of Brazil, our results in terms of returns to scale differ from the ones derived by Seroa da Motta and Moreira (2006) using DEA techniques. Using data on 107 operators (both regional and local) over the 1998-2002 period, they find returns to scale for the regional companies of about 2.5. The discrepancy between the two sets of results may be explained by the different sample sizes (our sample contains 26 regional operators and cover the period between 1996 and 2004) but also by the use of different techniques (regression analysis versus DEA). Cubbin and Tzanidakis (1998) compare regression and Data Envelopment Analysis techniques, and note that these techniques do not always end up with similar results especially when small sample sizes are used.

Because estimated returns at the sample mean (i.e., for the utilities' services with average characteristics) may be misleading, we report estimated returns for different groups of utilities. We report estimated returns to production density, estimated returns to customer density, and estimated returns to scale, for utilities classified in either small, medium, or large sized utilities, with respect to: (a) total volume of water produced by the utility, (b) number of water connections served by the utility, (c) volume of water produced per residential customer, and (d) number of customers per kilometre of water supply network.[23] Estimated returns for Brazil, Colombia, Moldova, and Vietnam are shown in tables 6, 7, 8, and 9 respectively.

We find similar trends in the four countries. In particular, we observe that estimated returns to scale decrease with utility size, as measured by total volume of water produced or number of connections served. Also, in most cases, the larger the volume of water or wastewater produced per residential customer, the lower the returns to scale. In Brazil, we cannot reject the null of constant returns to scale in all cases, with estimated returns lower than 1 in most cases (even if not statistically different from 1). In Colombia, we find significant economies of scale for all groups of WSS utilities. In Moldova, we find evidence of economies of scale

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[22] The result that the WSS industry in Brazil exhibit constant returns to scale does not rule out the possibility that this industry has natural monopoly characteristics. Indeed, economies of scale are a sufficient but not a necessary condition for a natural monopoly (Joskow, 2005).

[23] Water utilities serve also industrial and/or institutional customers so the volume produced per residential customer may vary significantly from one water utility to the other. We consider the ratio of total volume produced per residential customer instead of total volume of water sold to residential users per customer because the latter was not available in the four countries.

for small WSS utilities, but we cannot reject the null hypothesis of constant returns to scale for the large WSS utilities. The same kind of results is obtained for Vietnam: we find significant economies of scale for smaller water utilities.

In table 10, we report estimated returns to scale at the sample mean of each year. Estimated returns are found almost constant over the period in Brazil. The test of constant returns to scale cannot be rejected in all years. In Colombia, WSS utilities exhibit increasing returns to scale in 2003 and 2004. We find significant economies of scale in Moldova between 1996 and 2004, with returns to scale increasing over time, coinciding with a period in which the quantity and quality of water and sewerage services is steadily declining. In Vietnam, we also find significant economies of scale, but slightly lower at the end of the period than at the beginning.

6. Conclusions and policy implications

Using data from the IBNET database, we estimate measures of density and scale economies in four countries (Brazil, Colombia, Moldova and Vietnam) that differ substantially in economic development, piped water and sewerage coverage and characteristics of the utilities operating in the different countries. The analysis leads us to the following findings.

First, we find evidence of economies of scale in three of the four countries: Colombia, Moldova, and Vietnam. For the regional WSS utilities operating in Brazil, we cannot reject the hypothesis of constant returns to scale. The largest returns to scale at the mean (i.e., for the service with the average characteristics) are obtained for Moldova (1.26). WSS utilities operating in this country are on average small (compared to the size of utilities in the three other countries), with an average served population of 30,000 persons. The second largest returns to scale are estimated for Vietnamese water utilities (1.16), which serve on average a population of 142,000, followed by Colombian WSS utilities (1.11) which serve 229,000 inhabitants. In Brazil, we find evidence of constant returns to scale for the full set of regional WSS companies that serve on average a population of about 4 million.

The evidence seems to suggest that the very large size of the Brazilian regional WSS utilities may result in X inefficiencies. As utilities become larger, the increase in the administrative costs to run these large utilities may outweigh the gains in the unit costs of service provision. Feigenbaum and Teeples (1983) notice that lack of economies of scale can be due to the fact that such utilities may offer a broader range of services which would raise unit costs. In the case of Brazil, the regional utilities offer both water and sewerage collection and increasingly sewerage treatment services. To see in how far this hypothesis can be tested, we estimated returns to scale for smaller (municipal) companies in Brazil. IBNET contains data on 426 Brazilian municipal WSS utilities over the period between 2000 and 2004. The average municipal WSS utility in Brazil serves a population of 174,000 persons (which is in between the size of the average Vietnamese and Colombian utilities, see table 2). We estimate returns to production density, returns to customer density, and returns to scale, at the mean, on the sample of regional WSS utilities and on the sample of municipal WSS utilities, over the 2000-2004 period. Yet, for both municipal and regional WSS companies, we cannot reject the hypothesis of constant returns to scale (see table A6 in Appendix).

Secondly, few utilities in developed countries are characterized by economies of scale. Brazil, which is the richest country in the sample of four case studies, does not exhibit economies of scale for both municipal and regional WSS companies, as the hypothesis of constant returns to scale can not be rejected. From the latter results, it seems that, not only the size of the utilities but also the country's level of economic development, may explain that water and sewerage services do not necessarily operate under increasing returns to scale, similar to what was found in more developed countries (see the literature review in the introduction). Utilities in more developed countries may provide more water supply and wastewater collection and treatment services, services of better quality (universal coverage, 24-hour supply, quality of drinking water) and tend to operate in more regulated environments (possibly due to increased regulation of an environmental and economic nature, including labor regulation).[24] The provision of a greater number of higher quality water supply and sewerage services may increase administrative costs. High coverage levels that typically increase with development status will require the utilities to expand their network to more remote areas which may be reflected in lower network density of consumers, which is much lower in Brazil than in Colombia or Vietnam. The number of case studies in this study is limited to four, and hence a future area of research could be an analysis to investigate the

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[24] In Moldova (where we estimate the highest returns to scale), the quality of the water service is known to be quite deficient, in terms of population coverage and average duration of supply in particular (Moldova Apă-Canal Association, 2004). Unfortunately, information on average duration of supply and number of pipe breaks are not available for Brazilian water utilities.

relationship between level of economic development and economies of scale, and under what conditions economies of scale turn into diseconomies of scale.

Thirdly, economies of customer density are measured by how costs change if total water produced and the number of customers increases, under the assumption that the network length is constant. The effect of adding new customers shows diseconomies of consumer density in Brazil and Colombia, and economies of consumer density in Moldova and Vietnam – suggesting that there might be a turning point where positive network effects seem to disappear. Both Brazil and Colombia have achieved high coverage rates. The remaining households may be more difficult to serve with water and sanitation services (for instance, because they live in the periphery of the network system), resulting in higher costs to serve each additional customer.

Fourthly, the presence of economies of scale in the delivery of water supply and sewerage services is one of the major rationales for economic regulation in the sector. Yet, the question arises how "natural" natural monopolies are. The fact that economies of scale change over time, and that they may decline when the countries' economies become more developed suggests that regulation has to adapt to the dynamic environment in which it is operating.

In countries that typically have very high access rates, economies of scale tends to decrease and can turn into diseconomies of scale. In such circumstances, marginal cost pricing may result in prices that are above the full (average) cost of service, giving utilities the possibility to earn excess profits. The opposite tends to hold true when the sector is characterized by increasing returns to scale, when the marginal cost of service tends to be below the average cost of service, making it difficult for the utilities to achieve full cost recovery. Yet, by pricing against average cost, consumers (including poor consumers) will have to pay tariffs that are higher than efficient prices. In such circumstances, regulators have to protect the consumer, but also the utility's financial viability. The context of regulation in such an environment can further be affected by the degree of monopoly power in the water supply and/or sanitation market. In some countries with increasing returns to scale, water supply access rates may be relatively low (as was evident in the two lower-income countries in the sample: Vietnam and Moldova). In such cases, the utilities are not the only water supply providers and piped water tends to be a service with close substitutes. In such cases, contestability may exist in the water supply market for certain customer groups in certain localities over certain periods of time. Nevertheless, the regulator still has the obligation to protect consumers, even if at certain times certain utilities' consumers may be able to exercise their consumer sovereignty. Design of regulatory systems should take these features into account; as copying regulatory regimes and practices from developed countries to developing ones may not necessarily be very appropriate.

The results of this study show that the cost structure of the water and wastewater sector varies significantly between countries and within countries, and over time. Hence, a one-size-fit-all solution to regulating the sector is not going to be necessarily very successful as it is obvious that what type of regulation is needed and how effective it will be, depends on the organization of the sector itself, the environment in which the sector operates and the factor time.

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Tables

Table 1. GNI Atlas and Inflation (GDP Deflator), source: World Bank.

	Annual GNI per capita (Atlas method)(a), in US dollars				Inflation, GDP deflator			
	Brazil	**Colombia**	**Moldova**	**Vietnam**	**Brazil**	**Colombia**	**Moldova**	**Vietnam**
1996	4,320	-	480	-	100.00	-	100.00	-
1997	4,720	-	500	340	108.22	-	112.55	100.00
1998	4,610	-	470	350	113.51	-	118.86	108.84
1999	3,900	-	410	360	119.96	-	172.20	115.08
2000	3,670	-	390	380	129.98	-	219.27	119.00
2001	3,110	-	400	-	139.65	-	245.78	-
2002	2,680	-	470	-	153.85	-	269.93	-
2003	2,760	1,810	590	-	176.91	100.00	310.06	-
2004	3,090	1,810	710	-	-	107.06	334.72	-

Note:
(a) The Atlas conversion method is a smoothing algorithm devised by the World Bank to reduce the impact of exchange rate fluctuations. This applies a conversion factor that averages the exchange rate for a given year and the two preceding years, adjusted for differences in rates of inflation between the country, and through 2000, the G-5 countries (France, Germany, Japan, the United Kingdom, and the United States). From 2001, these countries include the Euro Zone, Japan, the United Kingdom, and the United States.

Table 2. Descriptive statistics for the four countries

	Brazil	Colombia	Moldova	Vietnam
Number of utilities	26	228	39	67
Period covered	1996-2004	2003-2004	1996-2004	1997-2000
Average volume of water produced per utility (million cubic meters per year)	395	22	4	13
Average population served per utility (thousands)	3,784	229	30	142
Average length of the water distribution network (km)	10,715	322	90	166
Population coverage (population supplied/total population of the area)	0.86	0.95	0.63	0.48
Number of customers per kilometre of network	376	664	275	788
Average share of total volume sold to residential users per utility	-	0.83	0.80	0.69
Average duration of supply (hours per day)	-	-	14	18
Number of pipe breaks per kilometre of network per year	-	-	4.40	4.33
Share of contracted out services costs	0.14	0.10	0.03	-
Share of energy costs	0.11	0.27	0.29	0.32
Share of labor costs	0.40	0.37	0.37	0.31

Table 3. First-order coefficients of cost functions (standard errors in parentheses)

		Brazil$^{(a)}$	**Colombia**	**Moldova**	**Vietnam**
Volume of water produced	y_{ws}	0.829*** (0.059)	0.662*** (0.056)	0.957*** (0.032)	0.613*** (0.060)
Price of contracted out services	w_c	0.150*** (0.003)	0.142*** (0.006)	0.058*** (0.004)	-
Price of energy	w_e	0.114*** (0.002)	0.322*** (0.007)	0.376*** (0.009)	0.320*** (0.006)
Price of miscellaneous factors	w_o	0.434*** (0.003)	0.344*** (0.008)	0.520*** (0.008)	0.475*** (0.007)
Length of the water distribution network	*len*	0.109** (0.047)	0.064 (0.060)	0.073 (0.092)	0.058** (0.024)
Duration of supply	*dur*	-	-	0.009 (0.027)	-0.179*** (0.058)
Volume sold/volume produced	*eff*	0.009 (0.047)	-0.165** (0.080)	-	-0.099* (0.059)
Share of metered connections	*mco*	0.020 (0.034)	0.091 (0.073)	-0.002 (0.012)	0.004 (0.167)
Number of towns served	*ntow*	0.054 (0.064)	-	-	-
Number of pipe breaks	*pbr*	-	-	-0.014 (0.019)	-0.012 (0.009)
Population served	*pop*	0.108* (0.060)	0.224*** (0.076)	-0.041 (0.071)	0.340*** (0.080)
Proportion of total volume sold to residential users	*vres*	-	-0.423* (0.249)	-	-0.071 (0.099)

Note:
(a): *, **, *** indicate that the estimated elasticity is statistically significant at the 10 percent, 5 percent, and 1 percent level respectively.

Table 4. Own-price elasticities and Morishima elasticities of substitution computed at the sample mean (standard errors in parentheses)

		Brazil(a)	Colombia	Moldova	Vietnam
		Own-price elasticities (ε_{jj})			
Contracted out services	ε_{cc}	-0.252***	-0.109***	-0.145***	-
		(0.023)	(0.041)	(0.037)	
Energy	ε_{ee}	-0.199***	-0.129***	-0.222***	-0.262***
		(0.028)	(0.025)	(0.016)	(0.022)
Labor	ε_{ll}	-0.096***	-0.245***	-0.213***	-0.295***
		(0.016)	(0.018)	(0.019)	(0.014)
Miscellaneous	ε_{oo}	-0.136***	-0.332***	-0.128***	-0.342***
		(0.008)	(0.019)	(0.010)	(0.008)
		Morishima elasticities of substitution (σ_{jm})			
Contracted out services vs. energy	σ_{ce}	0.285***	0.069	0.215***	-
		(0.032)	(0.048)	(0.050)	
Contracted out services vs. labor	σ_{cl}	0.166***	0.381***	0.347***	-
		(0.040)	(0.049)	(0.072)	
Contracted out services vs. miscellaneous	σ_{co}	0.233***	0.367***	0.148***	-
		(0.016)	(0.047)	(0.038)	
Energy vs. labor	σ_{el}	0.109***	0.314***	0.384***	0.377***
		(0.043)	(0.033)	(0.034)	(0.029)
Energy vs. miscellaneous	σ_{eo}	0.209***	0.416***	0.181***	0.522***
		(0.016)	(0.027)	(0.014)	(0.015)
Labor vs. miscellaneous	σ_{lo}	0.204***	0.491***	0.192***	0.551***
		(0.016)	(0.027)	(0.017)	(0.016)

Note:

(a): *, **, *** indicate that the estimated elasticity is statistically significant at the 10 percent, 5 percent, and 1 percent level respectively.

Table 5. Measure of returns to density and returns to scale computed at the sample mean (standard errors in parentheses)

		Brazil	**Colombia**	**Moldova**	**Vietnam**
Returns to production density[(a)]	R_{pd}	1.389*** (0.085)	1.688*** (0.235)	1.498*** (0.039)	1.549*** (0.096)
Returns to customer density	R_{cd}	1.077 (0.062)	1.068 (0.068)	1.332*** (0.072)	1.248*** (0.062)
Returns to scale	RTS	0.990 (0.045)	1.112*** (0.022)	1.264*** (0.091)	1.158*** (0.052)

Note:
(a): *, **, *** indicate that the estimated return is significantly different from 1 at the 10 percent, 5 percent, and 1 percent level respectively.

Table 6. Returns to density and returns to scale for different classes of WSS utilities in Brazil (standard errors in parentheses)

	Returns to production density[(a)]	Returns to customer density	Returns to scale
Total volume of water produced (million m^3/year)			
Low [31;123]	1.477*** (0.093)	1.097* (0.057)	1.040 (0.042)
Medium [131;255]	1.503*** (0.105)	1.088 (0.071)	0.987 (0.049)
High [268;2,600]	1.232** (0.118)	1.049 (0.095)	0.946 (0.071)
Total number of connections served (in thousands)			
Low [46;310]	1.477*** (0.093)	1.097* (0.057)	1.040 (0.042)
Medium [329;793]	1.521*** (0.109)	1.098 (0.072)	0.984 (0.049)
High [888;4,986]	1.219* (0.115)	1.039 (0.094)	0.949 (0.070)
Volume produced per residential customer (m^3/year)			
Low [65;80]	1.462*** (0.103)	1.049 (0.059)	1.016 (0.046)
Medium [82;102]	1.449*** (0.096)	1.072 (0.066)	1.001 (0.047)
High [103;188]	1.256** (0.101)	1.120 (0.077)	0.943 (0.051)
Number of customers per kilometre of network			
Low [189;279]	1.240*** (0.074)	1.038 (0.054)	1.030 (0.038)
Medium [304;413]	1.389*** (0.101)	1.097 (0.077)	0.968 (0.054)
High [418;761]	1.595*** (0.135)	1.098 (0.078)	0.970 (0.055)

Note:
(a): *, **, *** indicate that the estimated return is significantly different from 1 at the 10 percent, 5 percent, and 1 percent level respectively.

Table 7. Returns to density and returns to scale for different classes of WSS utilities in Colombia (standard errors in parentheses)

	Returns to production density[(a)]	Returns to customer density	Returns to scale
Total volume of water produced (million m^3/year)			
[0.946;4.255]	1.893*** (0.330)	0.998 (0.074)	1.111*** (0.036)
[4.370;11.998]	1.440 (0.291)	1.012 (0.089)	1.127*** (0.032)
[12.172;453.556]	1.809*** (0.231)	1.203 (0.111)	1.097*** (0.016)
Total number of connections served (in thousands)			
[2.29;9.164]	1.956*** (0.296)	1.008 (0.071)	1.117*** (0.033)
[9.695;26.282]	1.322 (0.283)	1.014 (0.098)	1.129*** (0.038)
[30.823;1,395.735]	1.930*** (0.263)	1.188 (0.105)	1.089*** (0.017)
Volume produced per residential customer (m^3/year)			
[46;81]	2.257** (0.632)	1.147 (0.097)	1.109*** (0.028)
[84;112]	1.770*** (0.266)	1.083 (0.070)	1.108*** (0.020)
[115;170]	1.318 (0.212)	0.992 (0.083)	1.118*** (0.025)
Number of customers per kilometre of network			
[287;471]	1.590* (0.323)	0.926 (0.086)	1.090*** (0.030)
[508;736]	1.882*** (0.286)	1.046 (0.070)	1.118*** (0.027)
[747;1,269]	1.622*** (0.207)	1.296** (0.143)	1.136*** (0.025)

Note:
(a): *, **, *** indicate that the estimated return is significantly different from 1 at the 10 percent, 5 percent, and 1 percent level respectively.

Table 8. Returns to density and returns to scale for different classes of WSS utilities in Moldova (standard errors in parentheses)

	Returns to production density[(a)]	Returns to customer density	Returns to scale
Total volume of water produced (million m^3/year)			
[0.059;0.304]	1.524*** (0.044)	1.383*** (0.092)	1.385*** (0.117)
[0.305;0.599]	1.532*** (0.041)	1.362*** (0.077)	1.302*** (0.095)
[0.621;124.364]	1.432*** (0.049)	1.255*** (0.091)	1.121 (0.114)
Total number of connections served			
[22;930]	1.584*** (0.052)	1.389*** (0.096)	1.423*** (0.122)
[1,038;1,911]	1.479*** (0.038)	1.346*** (0.073)	1.288*** (0.092)
[1,912;38,730]	1.428*** (0.049)	1.267*** (0.092)	1.098 (0.120)
Volume produced per residential customer (m^3/year)			
[16;39]	1.504*** (0.037)	1.373*** (0.083)	1.344*** (0.101)
[40;55]	1.522*** (0.044)	1.350*** (0.077)	1.261*** (0.092)
[56;211]	1.444*** (0.045)	1.274*** (0.080)	1.171* (0.101)
Number of customers per kilometre of network			
[81;149]	1.512*** (0.041)	1.422*** (0.090)	1.275*** (0.103)
[150;227]	1.533*** (0.040)	1.353*** (0.075)	1.285*** (0.093)
[228;701]	1.435*** (0.050)	1.231*** (0.073)	1.217** (0.088)

Note:
(a): *, **, *** indicate that the estimated return is significantly different from 1 at the 10 percent, 5 percent, and 1 percent level respectively.

Table 9. Returns to density and returns to scale for different classes of Water utilities in Vietnam (standard errors in parentheses)

	Returns to production density[(a)]	Returns to customer density	Returns to scale
Total volume of water produced (million m^3/year)			
[0.036;2.528]	1.390*** (0.082)	1.426*** (0.104)	1.432*** (0.076)
[2.657;5.746]	1.456*** (0.086)	1.179*** (0.057)	1.133*** (0.049)
[5.925;278.552]	1.835*** (0.183)	1.156** (0.071)	0.962 (0.056)
Total number of connections served			
[200;509]	1.520*** (0.138)	1.490*** (0.128)	1.465*** (0.083)
[518;13,825]	1.463*** (0.086)	1.200*** (0.057)	1.164*** (0.052)
[14,885;281,601]	1.705*** (0.136)	1.110* (0.067)	0.946 (0.053)
Volume produced per residential customer (m^3/year)			
[26;62]	1.287*** (0.094)	1.124** (0.054)	1.143*** (0.051)
[64;83]	1.546*** (0.104)	1.206*** (0.055)	1.154*** (0.052)
[84;211]	1.784*** (0.184)	1.287*** (0.077)	1.100* (0.056)
Number of customers per kilometre of network			
[190;461]	1.567*** (0.140)	1.303*** (0.078)	1.282*** (0.061)
[469;798]	1.551*** (0.098)	1.175*** (0.058)	1.046 (0.043)
[892;2,384]	1.457*** (0.104)	1.163** (0.079)	1.097 (0.062)

Note:
(a): *, **, *** indicate that the estimated return is significantly different from 1 at the 10 percent, 5 percent, and 1 percent level respectively.

Table 10. Estimated returns to scale at the sample mean of each year

Year	Brazil	Colombia	Moldova	Vietnam
1996	0.989	-	1.216**	-
1997	0.994	-	1.216**	1.221***
1998	0.977	-	1.254***	1.166***
1999	0.990	-	1.228***	1.129**
2000	0.998	-	1.268***	1.131***
2001	0.987	-	1.273***	-
2002	0.985	-	1.284***	-
2003	1.001	1.125***	1.310***	-
2004	0.992	1.100***	1.326***	-

Note:
(a): *, **, *** indicate that the estimated return is significantly different from 1 at the 10 percent, 5 percent, and 1 percent level respectively.

Appendix

Table A1. Summary of data availability in the four countries[(a)]

	Variable name	Brazil	Colombia	Moldova	Vietnam
Number of utilities		26	228	39	67
Period covered		1996-2004	2003-2004	1996-2004	1997-2000
Set of factor prices					
Contracted out services	*c*	X	X	X	NA
Energy	*e*	X	X	X	X
Labor	*l*	X	X	X	X
Miscellaneous	*o*	X	X	X	X
Set of control variables					
Length of the water network	*len*	X	X	X	X
Duration of supply	*dur*	NA	NA	X	X
Volume sold/volume produced	*eff*	X	X	X	X
Share of metered connections	*mco*	X	X	X	X
Number of towns served by the water utility	*ntow*	X	X	X	X
Number of pipe breaks	*pbr*	NA	NA	X	X
Population served	*pop*	X	X	X	X
Share of total volume sold to residential users	*vres*	NA	X	X	X

Note:
(a): NA is for « not available ».

Table A2. Translog cost function estimation results – Brazil (1996-2004)
26 regional WSS companies, 213 observations

Variable	Coef.	Std Err	p-value	Variable	Coef.	Std Err	p-value
constant	0.416	0.0854	0.0000	w_e x *len*	-0.014	0.0044	0.0010
y_{ws}	0.829	0.0592	0.0000	w_e x *pop*	-0.013	0.0069	0.0530
w_e	0.114	0.0019	0.0000	w_e x *mco*	0.005	0.0049	0.3150
w_c	0.150	0.0028	0.0000	w_e x *ntow*	0.003	0.0015	0.0590
w_o	0.434	0.0035	0.0000	w_e x *eff*	-0.007	0.0077	0.3610
len	0.109	0.0466	0.0190	w_c x *len*	-0.016	0.0073	0.0270
pop	0.108	0.0596	0.0690	w_c x *pop*	0.004	0.0112	0.7250
mco	0.020	0.0345	0.5710	w_c x *mco*	0.031	0.0081	0.0000
ntow	0.054	0.0641	0.4020	w_c x *ntow*	0.000	0.0025	0.8490
eff	0.009	0.0471	0.8460	w_c x *eff*	-0.016	0.0127	0.1990
y_{ws} x y_{ws}	0.228	0.1122	0.0420	w_o x *len*	-0.009	0.0079	0.2500
w_e x w_e	0.075	0.0031	0.0000	w_o x *pop*	-0.099	0.0109	0.0000
w_c x w_c	0.087	0.0034	0.0000	w_o x *mco*	-0.010	0.0085	0.2250
w_o x w_o	0.180	0.0029	0.0000	w_o x *ntow*	0.006	0.0029	0.0420
w_e x w_c	-0.003	0.0019	0.0940	w_o x *eff*	0.013	0.0147	0.3750
w_e x w_o	-0.030	0.0013	0.0000	*year 1997*	-0.019	0.0088	0.0330
w_c x w_o	-0.037	0.0018	0.0000	*year 1998*	-0.064	0.0111	0.0000
len x len	-0.154	0.1043	0.1400	*year 1999*	-0.071	0.0113	0.0000
pop x pop	0.416	0.1577	0.0080	*year 2000*	-0.080	0.0122	0.0000
mco x mco	0.096	0.0803	0.2340	*year 2001*	-0.075	0.0127	0.0000
ntow x ntow	0.022	0.0496	0.6590	*year 2002*	-0.083	0.0136	0.0000
eff x eff	-0.065	0.1397	0.6410	*year 2003*	-0.058	0.0126	0.0000
len x pop	-0.135	0.0916	0.1390	*year 2004*	-0.079	0.0147	0.0000
len x mco	-0.016	0.0846	0.8460				
len x ntow	0.031	0.0438	0.4810				
len x eff	0.174	0.0853	0.0410				
pop x mco	0.040	0.0789	0.6140				
pop x ntow	0.013	0.0582	0.8240				
pop x eff	-0.133	0.1051	0.2060				
mco x ntow	0.014	0.0349	0.6900				
mco x eff	-0.064	0.0741	0.3880				
ntow x eff	-0.054	0.0536	0.3170				
y_{ws} x w_e	0.028	0.0066	0.0000				
y_{ws} x w_c	0.013	0.0101	0.2020				
y_{ws} x w_o	0.118	0.0096	0.0000				
y_{ws} x *len*	0.256	0.0814	0.0020				
y_{ws} x *pop*	-0.345	0.1275	0.0070				
y_{ws} x *mco*	-0.060	0.0579	0.3020				
y_{ws} x *ntow*	-0.054	0.0484	0.2620				
y_{ws} x *eff*	0.012	0.0951	0.9000				

Table A3. Translog cost function estimation results – Colombia (2003-2004)
48 WSS utilities, 78 observations

Variable	Coef.	Std Err	p-value	Variable	Coef.	Std Err	p-value
constant	0.641	0.0245	0.0000	w_e x *len*	-0.005	0.0157	0.7720
y_{ws}	0.662	0.0564	0.0000	w_e x *pop*	-0.075	0.0228	0.0010
w_e	0.322	0.0067	0.0000	w_e x *mco*	-0.034	0.0105	0.0010
w_c	0.142	0.0056	0.0000	w_e x *vres*	0.036	0.0364	0.3230
w_o	0.344	0.0084	0.0000	w_e x *eff*	0.066	0.0256	0.0100
len	0.064	0.0597	0.2830	w_c x *len*	-0.030	0.0121	0.0140
pop	0.224	0.0764	0.0030	w_c x *pop*	-0.067	0.0170	0.0000
mco	0.091	0.0729	0.2140	w_c x *mco*	-0.003	0.0078	0.7360
vres	-0.423	0.2494	0.0900	w_c x *vres*	0.028	0.0267	0.2990
eff	-0.165	0.0801	0.0390	w_c x *eff*	0.079	0.0189	0.0000
y_{ws} x y_{ws}	0.203	0.3091	0.5120	w_o x *len*	0.015	0.0149	0.3220
w_e x w_e	0.161	0.0066	0.0000	w_o x *pop*	-0.010	0.0232	0.6660
w_c x w_c	0.081	0.0042	0.0000	w_o x *mco*	0.011	0.0113	0.3330
w_o x w_o	0.105	0.0050	0.0000	w_o x *vres*	0.110	0.0398	0.0060
w_e x w_c	-0.034	0.0037	0.0000	w_o x *eff*	-0.093	0.0276	0.0010
w_e x w_o	-0.046	0.0035	0.0000	*year 2004*	-0.004	0.0149	0.7630
w_c x w_o	-0.023	0.0034	0.0000				
len x len	-0.146	0.1335	0.2740				
pop x pop	-0.619	0.3949	0.1170				
mco x mco	0.017	0.0962	0.8560				
vres x vres	-0.466	0.6000	0.4370				
eff x eff	-0.558	0.4468	0.2120				
len x pop	0.472	0.1953	0.0160				
len x mco	0.227	0.2075	0.2740				
len x vres	0.509	0.4324	0.2390				
len x eff	-0.128	0.1776	0.4710				
pop x mco	0.444	0.4192	0.2900				
pop x vres	0.165	0.6296	0.7930				
pop x eff	0.569	0.3425	0.0970				
mco x vres	0.277	0.4642	0.5510				
mco x eff	-0.215	0.3005	0.4740				
vres x eff	0.206	0.3822	0.5900				
y_{ws} x *we*	0.098	0.0192	0.0000				
y_{ws} x *wc*	0.095	0.0139	0.0000				
y_{ws} x *wo*	0.011	0.0193	0.5550				
y_{ws} x *len*	-0.275	0.1479	0.0630				
y_{ws} x *pop*	0.095	0.2998	0.7510				
y_{ws} x *mco*	-0.594	0.2915	0.0420				
y_{ws} x *vres*	-0.635	0.4597	0.1670				
y_{ws} x *eff*	-0.414	0.3095	0.1810				

Table A4. Translog cost function estimation results – Moldova (1996-2004)
38 WSS utilities, 237 observations

Variable	Coef.	Std Err	p-value	Variable	Coef.	Std Err	p-value
constant	1.282	0.0614	0.0000	w_e *x len*	-0.022	0.0063	0.0000
y_{ws}	0.957	0.0320	0.0000	w_e *x pop*	0.007	0.0097	0.4770
w_e	0.376	0.0087	0.0000	w_e *x pbr*	-0.016	0.0036	0.0000
w_c	0.058	0.0038	0.0000	w_e *x dur*	-0.003	0.0040	0.4300
w_o	0.520	0.0082	0.0000	w_e *x mco*	-0.008	0.0026	0.0010
len	0.073	0.0919	0.4260	w_c *x len*	0.003	0.0025	0.1970
pop	-0.041	0.0707	0.5610	w_c *x pop*	-0.006	0.0038	0.1110
pbr	-0.014	0.0186	0.4570	w_c *x pbr*	-0.003	0.0014	0.0260
dur	0.009	0.0273	0.7400	w_c *x dur*	-0.005	0.0016	0.0010
mco	-0.002	0.0125	0.8510	w_c *x mco*	-0.002	0.0010	0.1150
y_{ws} *x* y_{ws}	0.145	0.0240	0.0000	w_o *x len*	-0.006	0.0067	0.3730
w_e *x* w_e	0.142	0.0047	0.0000	w_o *x pop*	-0.083	0.0104	0.0000
w_c *x* w_c	0.028	0.0013	0.0000	w_o *x pbr*	-0.008	0.0035	0.0180
w_o *x* w_o	0.173	0.0029	0.0000	w_o *x dur*	-0.001	0.0042	0.7400
w_e *x* w_c	-0.010	0.0016	0.0000	w_o *x mco*	0.006	0.0027	0.0260
w_e *x* w_o	-0.074	0.0025	0.0000	*year 1997*	0.004	0.0198	0.8420
w_c *x* w_o	-0.010	0.0012	0.0000	*year 1998*	-0.012	0.0196	0.5310
len x len	0.175	0.0588	0.0030	*year 1999*	0.005	0.0204	0.8090
pop x pop	0.171	0.0779	0.0280	*year 2000*	-0.013	0.0233	0.5800
pbr x pbr	0.002	0.0102	0.8680	*year 2001*	-0.018	0.0269	0.4950
dur x dur	-0.012	0.0132	0.3440	*year 2002*	-0.046	0.0285	0.1060
mco x mco	-0.014	0.0055	0.0120	*year 2003*	-0.076	0.0290	0.0080
len x pop	-0.099	0.0449	0.0270	*year 2004*	-0.084	0.0301	0.0050
len x pbr	0.013	0.0169	0.4570				
len x dur	0.065	0.0276	0.0190				
len x mco	0.002	0.0108	0.8510				
pop x pbr	0.006	0.0242	0.7980				
pop x dur	-0.043	0.0324	0.1870				
pop x mco	-0.006	0.0163	0.7280				
pbr x dur	-0.014	0.0086	0.1050				
pbr x mco	0.003	0.0050	0.5340				
dur x mco	0.003	0.0069	0.6370				
y_{ws} *x* w_e	0.055	0.0060	0.0000				
y_{ws} *x* w_c	0.011	0.0026	0.0000				
y_{ws} *x* w_o	0.106	0.0062	0.0000				
y_{ws} *x len*	-0.011	0.0222	0.6240				
y_{ws} *x pop*	-0.082	0.0371	0.0270				
y_{ws} *x pbr*	-0.019	0.0120	0.1120				
y_{ws} *x dur*	0.014	0.0153	0.3560				
y_{ws} *x mco*	-0.005	0.0092	0.6080				

Table A5. Translog cost function estimation results – Vietnam (1997-2000)
49 Water utilities, 145 observations

Variable	Coef.	Std Err	p-value	Variable	Coef.	Std Err	p-value
constant	0.768	0.0570	0.0000	y_{ws} x w_e	0.020	0.0132	0.1310
y_{ws}	0.613	0.0604	0.0000	y_{ws} x w_o	0.032	0.0139	0.0220
w_e	0.320	0.0061	0.0000	y_{ws} x *len*	-0.035	0.0443	0.4340
w_o	0.475	0.0074	0.0000	y_{ws} x *pop*	0.149	0.1280	0.2440
len	0.058	0.0238	0.0140	y_{ws} x *pbr*	-0.008	0.0171	0.6430
pop	0.340	0.0799	0.0000	y_{ws} x *dur*	-0.038	0.0789	0.6290
pbr	-0.012	0.0086	0.1670	y_{ws} x *mco*	0.071	0.2076	0.7340
dur	-0.179	0.0582	0.0020	y_{ws} x *vres*	0.157	0.0961	0.1020
mco	0.004	0.1672	0.9790	y_{ws} x *eff*	0.013	0.1639	0.9340
vres	-0.071	0.0989	0.4760	w_e x *len*	0.030	0.0099	0.0030
eff	-0.099	0.0585	0.0910	w_e x *pop*	-0.019	0.0157	0.2280
y_{ws} x y_{ws}	-0.151	0.1133	0.1830	w_e x *pbr*	-0.007	0.0026	0.0110
w_e x w_e	0.134	0.0072	0.0000	w_e x *dur*	-0.006	0.0093	0.5310
w_o x w_o	0.107	0.0028	0.0000	w_e x *mco*	-0.053	0.0315	0.0890
w_e x w_o	-0.059	0.0034	0.0000	w_e x *vres*	0.008	0.0203	0.6960
len x len	0.056	0.0258	0.0310	w_e x *eff*	0.030	0.0258	0.2490
pop x pop	-0.052	0.1381	0.7060	w_o x *len*	-0.061	0.0093	0.0000
pbr x pbr	0.002	0.0034	0.5510	w_o x *pop*	0.041	0.0175	0.0190
dur x dur	-0.079	0.0476	0.0950	w_o x *pbr*	0.001	0.0030	0.6750
mco x mco	0.112	0.3770	0.7660	w_o x *dur*	0.052	0.0085	0.0000
vres x vres	0.153	0.2587	0.5550	w_o x *mco*	-0.183	0.0235	0.0000
eff x eff	0.210	0.2646	0.4270	w_o x *vres*	0.069	0.0218	0.0020
len x pop	0.082	0.0583	0.1600	w_o x *eff*	-0.066	0.0253	0.0090
len x pbr	-0.024	0.0099	0.0160	*year 1998*	-0.003	0.0057	0.6570
len x dur	0.021	0.0310	0.5000	*year 1999*	-0.005	0.0092	0.5620
len x mco	-0.223	0.0937	0.0170	*year 2000*	-0.022	0.0142	0.1180
len x vres	-0.340	0.1090	0.0020				
len x eff	-0.112	0.0744	0.1330				
pop x pbr	0.001	0.0174	0.9380				
pop x dur	-0.095	0.0788	0.2270				
pop x mco	-0.057	0.2262	0.8020				
pop x vres	0.046	0.0947	0.6250				
pop x eff	0.116	0.1767	0.5130				
pbr x dur	-0.018	0.0094	0.0540				
pbr x mco	0.032	0.0497	0.5230				
pbr x vres	-0.066	0.0307	0.0300				
pbr x eff	-0.115	0.0267	0.0000				
dur x mco	0.281	0.1152	0.0150				
dur x vres	0.441	0.1273	0.0010				
dur x eff	0.142	0.0945	0.1320				
mco x vres	-0.378	0.2646	0.1530				
mco x eff	-0.152	0.3162	0.6310				
vres x eff	0.165	0.2273	0.4680				

Table A6. Comparison between municipal and regional WSS utilities in Brazil.

	Municipal WSS utilities	**Regional WSS utilities**
Number of utilities	426	25
Period covered	2000-2004	2000-2004
Average volume of water produced per utility (million cubic meters per year)	18	409
Average population served per utility (thousands)	174	4,041
Average length of the water distribution network (km)	541	11,506
Population coverage (population supplied/total population of the area)	0.84	0.85
Number of customers per kilometre of network	344	364
Share of contracted out services costs	0.17	0.15
Share of energy costs	0.24	0.11
Share of labor costs	0.41	0.34
Estimated returns to production density(a,b)	1.36***	1.21**
Estimated returns to customer density	1.14***	1.04
Estimated returns to scale	1.00	1.09

Note:

(a): Returns to production density, returns to customer density, and returns to scale are computed at the sample mean.

(b): *,**,*** indicates that the estimated return is significantly different from 1 at the 10, 5, and 1% level, respectively.