# Measuring Economies of Vertical Integration in Network Industries: An Application to the Water Sector*

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**Abstract**

This paper provides a framework that aims at distinguishing the technological economies of vertical integration from the vertical economies resulting from an inefficient input allocation due to upstream market imperfections. To illustrate our analysis, we use consistent panel data econometric methods to estimate cost functions on a sample of North-American water utilities. Contrary to what has been found for other network industries (electricity and gas for instance), we show that the global and technological economies of vertical integration are not significant except for the smallest utilities.

**Keywords**: Vertical integration, water network, cost function, panel data.

**JEL Codes**: C33, L22, L95.

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# 1 Introduction

Unprecedented transformations aiming at introducing more competition into sectors traditionally considered as pure natural monopolies have been an important feature of the public policies in the two last decades. One of the key recommendation of policy-makers has been to broke up monopolies before introducing more competition.[1] Behind this recommendation is the idea that natural monopoly and potentially competitive parts of a utility should be separated to prevent competition distortions. In most of network industries, the result has been to introduce competition at the production stage while maintaining transmission and, in some cases, distribution as local monopolies.

However, it has been recently argued that vertical disintegration of utilities can result in cost efficiency losses if production stages are characterized by strong economies of vertical integration.[2] Identifying the determinants of economies of vertical integration (EVI) is however not straightforward. EVI may be first the consequence of market imperfections and monopoly power at the upstream stages of the production process: if there are market imperfections, input allocation at the downstream stage will be distorted resulting in higher costs. But a vertically integrated structure can also be a cost effective solution if there are substantial needs for coordination and adaptation across stages. This may occur if there are significant technological complementarities across production stages or if using intermediary markets involves high transaction costs.

A global measure of economies of vertical integration, as proposed by Kaserman and Mayo (1991) or Kwoka (2002), does not allow to distinguish the technological and transactional economies from those resulting from an inefficient allocation of inputs due to market imperfections at an upstream stage. Yet, identifying the sources of EVI may appear to be crucial in some cases. In particular, disintegration may only be cost effective if upstream markets are competitive enough. A regulatory authority should then promote a vertically disintegrated structure only if price distortions on the upstream markets can be limited. The conclusion given by a global measure of vertical integration could be subject to controversy in such a case. For network industries (e.g.

[1] The question of liberalization of these industries, its economic implications and political issues are also in the core of the structural reforms in the EU, see European Commission (1999).

[2] Interestingly, most of the empirical studies trying to assess the presence of economies of vertical integration have reported substantial cost efficiency gains for vertically integrated structures. Working on a sample of US electric utilities, Kaserman and Mayo (1991) have shown that the cost is on average 11.96 percent higher for vertically disintegrated services than for vertically integrated ones. Also working on a sample of US electric utilities, Kwoka (2002) concludes that disintegration may result in a substantial cost increase, 42 percent on average. Two recent studies suggest however that the economies of vertical integration might be lower. Nemoto and Goto (2004) using a panel of 9 Japanese utilities observed from 1981 to 1998, report a cost efficiency gain for the vertically integrated structure between 0.13 and 2.97 percent. Last, Jara-Díaz et al. (2004) based on a sample of Spanish electric utilities, conclude that joint generation and distribution may save 6.5% of costs.

electricity, water, gas) characterized by strong technological interdependencies between production and distribution stages, identifying the source of EVI is particularly important. Recently, Nemoto and Goto (2004) have proposed a framework to estimate those technological externalities by introducing the capital stock of the upstream stage into the downstream stage cost function. Whereas this econometric study is the first to be explicit about the sources of EVI, it however eludes market imperfections as a potential source of EVI. By separately estimating the cost functions of vertically integrated and non-vertically integrated structures and by imposing marginal cost pricing on the upstream market, we make possible the distinction between the two sources of EVI.

Within network industries, the water sector still seems to be a special case in which direct competition and production stage separation have not yet really been observed.[3] Water utilities are still viewed as natural monopolies that must be regulated by public authorities. This is quite surprising as there are important similarities between water and the other network utilities where competition has been successfully introduced.[4] As in gas and electricity, the production stage of the industry seems potentially competitive whereas the distribution stage presents some characteristics of a natural monopoly. The network of pipes is naturally monopolistic like the networks of pipes in gas and wires in electricity. So there is no obvious reason for limiting competition in any part of the production process which does not appear to be a natural monopoly, except if EVI are important. But as no measure of such economies have been yet published there is still no clear answer to the optimal organization of the water industry. One objective of this paper is to shed some light on this debate by providing an estimate of the EVI in the water industry.

The paper is organized as follows. In the next section, we discuss the nature of the EVI in network industries with a special emphasis on the water sector. Then, we present the cost model from which we derive the global and technological measures of the EVI. In the following section, we describe the database and our investigation area. Last, we present the result of the empirical application and we show that there are no significant global economies of vertical integration except for small water utilities. We also demonstrate that the technological economies are quite low in the water network industry.

[3]England is a special case. The 1998 Competition Act has opened up the scope for more competition in water industry. Inset appointments which allow the existing regulated water utility to be replaced by another for a specific site are now authorized. Common carriage which occurs when one service supplier shares the use of another's assets is also authorized by OFWAT.

[4]There are also important differences between networks but they cannot explain by themselves the absence of competition. For instance, it is claimed that the absence of competition could be related to the lack of a long-distance grid in water. But this lack can be the result of no competition in the past since incentives to connect to other monopolists' systems are minimal with captive consumers.

## 2 Structure of production and vertical integration

### 2.1 The nature of economies of vertical integration

If an industry is characterized by several successive production stages[5], a single firm may be able to produce the complementary products of these different stages more efficiently than several firms would do. Such industries present, at some stages, EVI, i.e. the total cost of producing is lower in a vertically integrated structure than in a disintegrated one. Sources of EVI, although difficult to identify, can be classified into three main categories: technological economies, transactional economies and economies resulting from an inefficient input allocation due to upstream market imperfections.

First, vertical integration may be a cost effective solution due to the presence of technological economies. These technological economies come from physical interdependencies in the production process. There are technological economies if there are economies of scope across different production stages, that is if there are important complementarities or coordination economies across stages. These coordination economies include a greater adaptability to non-anticipated events and a better information for taking a decision that is going to have an effect at different production steps. Typically, in networks, a joint optimization of production plant capacity and size of the transmission system will lead to technological economies. Costs can also be reduced if integration of firms results in a closer geographic proximity of production units. Finally, vertically integration can facilitate investment in specialized assets allowing to avoid the hold-up problem. One important drawback of vertical integration is that it may decrease flexibility. Moreover, vertical integration raises some capacity balancing issues. In the absence of alternative inputs supply, the integrated firm may be compelled to build excess upstream capacity to meet the downstream demand in all conditions.

Transactional economies, associated to the use of intermediary product markets, may be another important determinant of vertical integration. The transaction costs mainly correspond to coordination costs i.e. to cost reflecting the design, the negotiation and the enforcement of contracts between buyers and sellers. Transaction costs also involve costs related to the asset specificity, to the incomplete nature of contracts and to the problem of asymmetric information. The transactional economies may come from a reduction in opportunistic behavior in the bilateral exchange, and in an efficient conflict resolution machinery, Williamson (1985). However, an

[5] We may think to the usual distinction between production, transmission and distribution in the electric industry or in the telecommunication networks.

important limit to the presence of transactional economies is the size of the vertically integrated structure. Large integrated firms will result in important internal incentive problems. This is especially the case if the managerial objectives at each production stage are not aligned with the whole structure objective. In a vertical setting, a subordinate manager may have lower incentives to come up with good ideas to reduce production costs as this investment may by expropriated by the firm's owner, Grossman and Hart (1986). Hence, transactional economies will exist if the coordination gains overwhelm the internal incentive costs.

Other driving forces of vertical integration are market imperfections. In particular, if there are important scale economies at the production stage, the upstream firms may benefit from profit margins. This will result in an inefficient combination of inputs at the downstream stage. Cost efficiency may favor a vertically integrated structure in such a case. However, vertical integration, by aggregating monopoly positions may lead to need for heavier form of regulation especially for protecting final customers. Moreover, vertical integration may result in a foreclosure problem. Foreclosure refers to a dominant firm's denial of proper access to an essential good in order to extend a monopoly power from one market to another, see Hart et al. (1990) or Rey and Tirole (2003). The foreclosure issue does not seem to be the main market imperfection problem for the water sector since water suppliers usually operate on geographic separated markets.

In assessing the optimal degree of vertical integration in a network industry, it is important to distinguish the technological economies (non duplication of fixed costs, better coordination, ...), that favor a vertically integrated industry from those resulting from price distortions on markets for intermediate goods, that may favor vertically separated firms. It is crucial to separate and identify these two issues as it is clear that the welfare consequences of vertical integration will depend upon the motivation for vertical integration. Integration to take advantage of technological vertical economies will, other things equal, improve welfare.

## 2.2 Vertical integration in the water network industry

Vertically-integrated water utilities are still the norm in most of the countries. There are two main reasons justifying the persistence of such market structures. First, an important characteristic of water supply services is that they are local: the production plant and the distribution network are often very close (mainly because of network losses and alteration of the water quality during transportation). Second, quality is essential and introducing multiple water suppliers in a same distribution network may create some difficulties, Bisshop (2001). These difficulties include the compatibility of water treatments realized by different producers, the origin of water in the network, or the liability in case of sanitary problem.

Coordination between the delivery service and producers is also important, especially for the volume of water that must be injected into the network. The distribution stage may require from the production stage additional water flow in order to compensate for a low rate of network return or to adapt deliveries to peak-load demand. Each stage of the water supply process (production and distribution) is also constrained by pressurization facilities. Once again, a good coordination between the two stages is necessary to maintain a sufficient pressure at the tap of users. Other problems can arise depending on whether the network is meshed or in arborescence. In the first case, the water can circulate in all directions. In the second case, water flows thanks to gravity and the production stage must be located upstream.

### 2.3 Measuring economies of vertical integration in a multi-stage industry

Several studies (mostly focusing on the electric sector) have tried to assess the level of the EVI using different framework. First, some authors (Lee, 1995, Hayashi et al., 1997) have tested the cost separability of the different production stages. The issue addressed by these authors is in fact to test whether input proportions used to produce the final output depend or not on the price of the intermediate good. As mentioned by Kwoka (2002), this indirect test does not allow to properly measure the EVI.

Kaserman and Mayo (1991) have proposed to measure the EVI by evaluating the economies of scope in a multiproduct cost framework. The idea is that a fully vertically-integrated utility produces all stage outputs. By nullifying one output, the production cost specific to this output can be assessed. In a two-stage production process, Kwoka (2002) has adapted this framework in order to properly compare the costs of an integrated utility with the cost of a pure-distribution utility. Three major drawbacks emerge from this measure of the EVI. First, this approach requires to estimate a single cost function. The implicit assumption is that the data generating process of the cost of a utility does not depend on the vertical organization of the sector. In other words, the production technology and the estimated parameters are identical whether the firm is integrated, a pure-production utility or a pure-distribution utility. But this implicit assumption is not likely to hold as the production technology may strongly differ according to the vertical organization and hence so do the cost-minimizing program of the different utilities. Second, the measure for EVI proposed by Kaserman and Mayo (1991) and Kwoka (2002) is a global measure that does not allow to distinguish between technological determinants and input allocation distortions resulting from market imperfections. Last, because the definition of economies of scope involves zero output at some stage, using a translog cost function is not possible. The previous studies have estimated a quadratic cost function that imposes some constraints making the approximation of the cost function less flexible.[6] For these reasons, we propose to estimate a cost function specific to each type of utility. This requires to estimate a cost function for a vertically-integrated (VI) utility and cost functions for all types of non-vertically integrated (NVI) services.

Still in the electric utility context, Nemoto and Goto (2004) have recently proposed to measure the technological externalities by testing if the cost function of the transmission-distribution stage depends upon the capital used at the generation stage. This is a strong assumption since technological EVI may potentially have many other sources (for instance some variables inputs used at the upstream stage may also be used at the downstream stage, some economies of coordination between stages may also no depend upon the level of capital, etc.). Moreover, Nemoto and Goto (2004) only estimate a distribution cost function and they do not consider the effect of market imperfections as a potential motive for vertical integration.[7]

### 2.3.1 Cost structure for a vertically-integrated utility

In order to simplify the presentation of the model we consider a firm characterized by two production stages vertically related, indexed by $s = 1, 2$ and called the production and the distribution stage, respectively. The cost model can easily be extended to a higher number of successive stages.

At stage $s$, the utility uses a vector $X_s$ of $k_s$ inputs and we denote by $Z_s$ the capital and technical variables of the corresponding stage. We note $Y_1$ the intermediary output produced at the first stage, $Y_2$ the final output produced at the second stage, and $g$ the production function of the VI utility. In the water network industry, $Y_1$ and $Y_2$ represent the volume of water respectively withdrawn and sold to final users. The overall cost minimization program of the VI

[6] The main limitation of the quadratic functional form is that it is not linearly homogeneous in input prices. Such a property can be imposed on the translog form through a set of parameter constraints, but this cannot be done in the quadratic case without loosing its flexibility (Caves, Christensen, and Tretheway 1980). Moreover, the translog function allows the analysis of the underlying production structure (homogeneity, separability, economies of scale, etc.) through simple tests on estimated parameters and the first order coefficients can be directly interpreted as cost-product elasticities (at the approximation point). Last, the number of parameters to be estimated is larger for the quadratic function than for the translog thanks to constraints imposed on the translog function (such as homogeneity in factor prices and symmetry).

[7] Moreover, Nemoto and Goto (2004) model the electricity input received from the production stage as being quasi-fixed at the transmission-distribution stage. Instead, we propose to introduce the relationship between the two stages through the price of water sold by the production to the distribution stage. Identification of technical EVI is then made possible by equalizing the water price to the marginal cost of the production stage, which depends among others on the production stage capital stock. Hence, our proposed measure of technological EVI takes implicitly into account all technical characteristics of the production stage, including the capital level.

utility writes: $\min_{X_1,X_2} \sum_{k_1} w_{1k_1} \times X_{1k_1} + \sum_{k_2} w_{2k_2} \times X_{2k_2}$ s.t. $Y_2 = g^{vi}(X_1, X_2|Z_1, Z_2)$, where $w_1$ and $w_2$ are respectively the factor prices of stages 1 and 2. The overall cost function of the VI utility writes:

$$C^{vi}(Y_2, w_1, w_2|Z_1, Z_2). \tag{1}$$

The cost minimization requires to equalize the relative marginal productivity of inputs at each stage, but also across the two successive stages. Equalization of relative marginal productivity of inputs across stages is specific to a vertically integrated structure.

### 2.3.2 Cost structure for non-vertically integrated utilities

Let us assume now that the two stages are not integrated. The gross output $Y_1$ is produced by a utility (production utility) and $f_1$ is the associated production function. Then $Y_1$ is sold to another separated utility (distribution utility) which uses it as an input of the distribution stage with the production function $f_2$.

We first consider the production utility, $s = 1$. The cost minimization program simply writes: $\min_{X_1} \sum_{k_1} w_{1k_1} \times X_{1k_1}$ s.t. $Y_1 = f_1^{nvi}(X_1|Z_1)$. The non-vertically integrated production (NVI production) cost function is:

$$C_1^{nvi}(Y_1, w_1|Z_1) = \sum_{k_1} w_{1k_1} \times \widehat{X}_{1k_1}^{nvi}(Y_1, w_1|Z_1), \tag{2}$$

where $\widehat{X}_1^{nvi}(Y_1, w_1|Z_1)$ represent the input derived demands.

The cost minimization of the production stage requires to equalize the relative marginal productivity of inputs used at this stage.

Now we consider a distribution utility that must buy the intermediate good $Y_1$ at a unit price $w_{Y_1}$. For such a water distribution utility, the cost minimization program writes: $\min_{Y_1,X_2} w_{Y_1} Y_1 + \sum_{k_2} w_{2k_2} \times X_{2k_2}$ s.t. $Y_2 = f_2^{nvi}(Y_1, X_2|Z_2)$. The non-vertically integrated distribution (NVI distribution) cost function is the following:

$$C_2^{nvi}(Y_2, w_{Y_1}, w_2|Z_2) = w_{Y_1} \times \widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2) + \sum_{k_2} w_{2k_2} \times \widehat{X}_{2k_2}^{nvi}(Y_2, w_{Y_1}, w_2|Z_2). \tag{3}$$

where $\widehat{X}_2^{nvi}(Y_2, w_{Y_1}, w_2|Z_2)$ is the derived demand in second stage inputs and $\widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2)$ the derived demand in intermediary good.

The cost minimization of the distribution stage requires to equalize the relative marginal productivity of inputs used at this stage. These inputs include the intermediate good, $Y_1$. The

VI and the NVI structures are equivalent if and only if the two following conditions are satisfied:

$$w_{Y_1} = \frac{\partial}{\partial Y_1} C_1^{nvi}(Y_1, w_1|Z_1) \tag{4}$$

$$g^{vi}(X_1, X_2|Z_1, Z_2) = f_2^{nvi}(f_1^{nvi}(X_1|Z_1), X_2|Z_2) \tag{5}$$

that is if the intermediate good in a (non-vertically integrated) production utility is priced at its marginal production cost and if the production function of the VI structure can be decomposed into the two successive NVI stages. As we do not impose condition (5) to hold, we take into account the fact being vertically integrated or not may result in different technologies of production (due for instance to the specificity of assets or the need to solve internal incentive problems in the vertically integrated case).

Finally, the overall cost for a NVI structure is equal to the variable cost of the production and the distribution stages less the water expenses of the distribution utility. The water expenses correspond, in fact, to a monetary transfer from the distribution utility toward the production utility that cancel out when considering the whole vertical structure. Moreover, as the produced volume $Y_1$ supplied to the distribution utility corresponds to the optimal derived demand in intermediate good of the distribution utility $\widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2)$, the overall cost for a NVI structure is:

$$\begin{aligned} C^{nvi}(Y_2, w_{Y_1}, w_1, w_2|Z_1, Z_2) =& C_1^{nvi}(\widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2), w_1|Z_1) + C_2^{nvi}(Y_2, w_{Y_1}, w_2|Z_2) \\ & - w_{Y_1} \times \widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2) \\ =& \sum_{k_1} w_{1k_1} \times \widehat{X}_{1k_1}^{nvi}(\widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2), w_{Y_1}, w_1, w_2|Z_1, Z_2) \\ & + \sum_{k_2} w_{2k_2} \times \widehat{X}_{2k_2}^{nvi}(Y_2, w_{Y_1}, w_2|Z_2). \end{aligned} \tag{6}$$

#### 2.3.3 Economies of vertical integration

A direct comparison of $C^{vi}$ and $C^{nvi}$ allows to measure *the global economies of vertical integration*, that is economies of integration resulting from both technological effects and from an inefficient input allocations.[8] The global economies of vertical integration (GVI) are measured by the ratio:

$$\text{GVI} = \frac{C^{vi}(Y_2, w_1, w_2|Z_1, Z_2)}{C^{nvi}(Y_2, w_{Y_1}, w_1, w_2|Z_1, Z_2)}. \tag{7}$$

[8] It is clear that if the vertical organization choice is not random, such a direct comparison will suffer from a sample selection bias. A consistent estimation of the cost functions requires in such a case to control for differences inducing the vertical organization choice. We will more formally address this issue in the empirical part of this article.

If GVI <1 then the vertical structure is characterized by global economies of vertical integration. In other words, given the level of final output to be produced $Y_2$, the price of inputs $(w_1, w_2)$ and the price of the intermediate good $w_{Y_1}$, a vertically structure will produce at a lower cost. On contrary, if GVI >1, there are diseconomies of vertical integration and two separated utilities are more efficient. Finally, if GVI =1, there are no economies nor diseconomies of vertical integration.

As mentioned previously, such a measure of economies of vertical integration mixes the technological effects (interdependence between the two stages in the case of integrated structure and asset specialization in the case of non-integrated structure for instance) with the market effects (market for intermediate good non competitive resulting in a non efficient allocation of inputs at the second stage). In order to identify these market and technological effects, we propose the following approach: first we compute the total cost of a non-vertically structure while imposing the intermediate good to be sold at its marginal production cost and, second we compare this cost to the cost of a vertically integrated structure. First, we consider the NVI production utility. Following equation (2), the cost function writes $C_1^{nvi}(Y_1, w_1|Z_1)$. Let us assume that the intermediate good is be sold at its marginal production cost. In such a case following equation (4) we have:

$$w_{Y_1} = \frac{\partial}{\partial Y_1} C_1^{nvi}(Y_1, w_1|Z_1). \tag{8}$$

As the right hand-side of this equation depends upon $Y_1$, the unit price for the intermediary good will be a complex function of the quantity. It is important to notice that this condition does not necessary mean that the market for the intermediate good is assumed to be perfectly competitive. A fixed charge may be used by the productionutility to recover losses in case of increasing return to scale. But in that case, the fixed charge does not have any effect on input allocation at the distribution stage, and what really matters is the marginal price. The fixed charge is just a transfer from the distribution utility toward the production utility that will cancel out when evaluating the total cost of the NVI structure. Condition (8) defines the price of the intermediate good as a function of the first-stage output and first-stage input prices:

$$w_{Y_1} = w_{Y_1}(Y_1, w_1|Z_1). \tag{9}$$

Let us now consider the NVI distribution utility. The derived demand in $Y_1$ is $\widehat{Y}_1^{nvi}(Y_2, w_2, w_{Y_1}|Z_2)$, see equation (3). Marginal cost pricing at the first stage gives:

$$\widetilde{Y}_1^{nvi}(Y_2, w_1, w_2|Z_1, Z_2) = \widehat{Y}_1^{nvi}(Y_2, w_2, w_{Y_1}(Y_1, w_1|Z_1)|Z_2). \tag{10}$$

The total cost, net of the water purchase cost, for a NVI distribution utility with marginal cost pricing at the first stage writes:

$$\begin{aligned}\sum_{k_2} w_{2k_2} \times \widehat{X}^{nvi}_{2k_2}(Y_2, w_2, w_{Y_1}|Z_2) &= \sum_{k_2} w_{2k_2} \times \widehat{X}^{nvi}_{2k_2}(Y_2, w_2, w_{Y_1}(Y_1, w_1|Z_1)|Z_2) \\ &= \sum_{k_2} w_{2k_2} \times \widehat{X}^{nvi}_{2k_2}(Y_1, Y_2, w_1, w_2|Z_1, Z_2) \\ &= \sum_{k_2} w_{2k_2} \times \widehat{X}^{nvi}_{2k_2}(\widetilde{Y}^{nvi}_1(Y_2, w_1, w_2|Z_1, Z_2), Y_2, w_1, w_2|Z_1, Z_2) \\ &= \widetilde{C}^{nvi}_2(Y_2, w_1, w_2|Z_1, Z_2).\end{aligned} \tag{11}$$

Using equations (2) and (10), the cost function of the NVI producer utility writes as a function of $Y_2$, $w_1$, $w_2$, $Z_1$ and $Z_2$:

$$\widetilde{C}^{nvi}_1(Y_2, w_1, w_2|Z_1, Z_2) = C^{nvi}_1(\widetilde{Y}^{nvi}_1(Y_2, w_1, w_2|Z_1, Z_2), w_1|Z_1). \tag{12}$$

The overall cost of a NVI structure, imposing condition (8) to hold, writes:

$$\widetilde{C}^{nvi}(Y_2, w_1, w_2|Z_1, Z_2) = \widetilde{C}^{nvi}_1(Y_2, w_1, w_2|Z_1, Z_2) + \widetilde{C}^{nvi}_2(Y_2, w_1, w_2|Z_1, Z_2). \tag{13}$$

Condition (8) makes the overall cost of a NVI structure no more depends on the price on the intermediate good $w_{Y_1}$. Moreover imposing this condition suppresses any misallocation of inputs due to market imperfection. Thus, any remaining economies of vertical integration are now purely technological. The *technological economies of vertical integration*, TVI, are measured by the ratio:

$$\text{TVI} = \frac{C^{vi}(Y_2, w_1, w_2|Z_1, Z_2)}{\widetilde{C}^{nvi}(Y_2, w_1, w_2|Z_1, Z_2)} \tag{14}$$

If TVI$<$1 then the vertical structure is characterized by technological economies of vertical integration. If TVI$>$1, there are technological diseconomies of vertical integration. Finally, if TVI$=$1, there are no technological economies nor diseconomies of vertical integration.

It should be noticed that the economies of vertical integration we have defined (both the global and the technological ones) are based on a comparison of the cost efficiency of the alternative vertical structures. One may argue that the normative implications derived from these measures may be subject to caution as a cost minimizing vertical structure may not be the one maximizing the social welfare. In particular, if the upstream market imperfections are diminished due to vertical integration, this may constitute a benefit for the integrated structure. However, society might be much worser off if the upstream market power falls in the hands of a vertically integrated industry. Indeed, due to possible technical efficiencies, the market power might be larger in the case of an integrated firm than in the case of two separated firms. But one specific characteristic of the water sector is that the final user market is usually regulated by a public authority. This is for instance the case in the US where State Public Service Commissions exercise their authority and influence to ensure that consumers receive safe, reliable and reasonably priced services from financially viable and technically competent utilities. If the final water market is highly regulated, what really matters in terms of social welfare is to minimize production costs. In such a case, the $GVI$ and $TVI$ indexes will provide the public authority with an indication of the optimal vertical structure.

# 3 Vertical integration and costs for Wisconsin water utilities

The Wisconsin is quite typical of the North-American water industry. The water utilities are on average small. In 2003, there were approximately five hundred water systems in Wisconsin delivering water to less than three thousand customers, on average. Most of the water services are municipally owned: in 2003, only 6 over the 512 utilities were privately owned. The Wisconsin water utilities are regulated by the Public Service Commission of Wisconsin (PSC). The general principle of regulation for Wisconsin water utilities is a rate of return framework. However, in practice different regulatory schemes are implemented (regular rate of return, hybrid rate of return and interim price cap), see Aubert and Reynaud (2005) for further details.

## 3.1 Vertically and non-vertically integrated water utilities in the Wisconsin

Following the theoretical model, we consider a two-stage production model. The Production & Treatment stage, P&T, corresponds to resource extraction, transfer from the source of supply to the production facilities and treatment of raw water. The Transmission & Distribution stage, T&D, includes all the operations involved into the the transmission of water to final customers through distribution mains and the customer services.

The PSC regulates three classes of water utilities defined by the number of final users. Due to data limitations, we were not able to keep in our sample the smallest utilities. We finally have in our sample a balanced panel of 211 services observed yearly from 1997 to 2000. The vertically versus non-vertically utility groups are defined as follows:

- *Vertically-integrated (VI) utilities.* These utilities neither buy water from a wholesale supplier nor resale water to another service. They are 171 pure vertically integrated utilities.

- *Non-vertically integrated (NVI) distribution utilities.* 23 utilities report a positive quantity of water bought to another service but only 15 have been considered as NVI distribution services. For the 15 services kept in our sample, the ratio water bought to water produced is higher than 95% (11 services depend exclusively on a wholesale water supplier) whereas for the 8 dropped services, water brought to another utility is only a secondary source of water.

- *Non-vertically integrated (NVI) production utilities.* 23 services report a positive quantity of water sold to another water utility. In order to avoid any double counting, 6 services also buying water from another services have been dropped. For the 17 remaining (NVI production services), the ratio water volume sold to another service to total water volume sold varies from 1% to 35%.[9]

From 1997 to 2000, 15.9 million of gallons of water have been sold on average each year by a water utility to another in the Wisconsin. This volume represents around 7.6% of the total water distributed. Both resale and final user water prices are regulated by the PSC. For instance, there exist some specific rules (the Purchased Water Adjustment Clause) that allow a supplier to revise its water price in case of an increase of the water wholesale price. The average water resale price was for this period 1.26 US$ per thousand of gallons (Mgals), compared to the average water price for residential and industrial user, 2.73 and 1.53 US$ per Mgals respectively.

As mentioned previously, one possible positive effect of vertical separation could be to induce more internal efficiency Grossman and Hart (1986). In the specific case of the water industry, vertical separation may induce more network efficiency at the downstream stage and so, more water savings. Due to market imperfections on the upstream market, the marginal price of purchased water can be higher than the first stage marginal cost of production. Hence, the downstream firm may face more incentives to reducing network water losses.

In Table 1, we compare the network efficiency of water utilities according to the proportion of water purchased to another service. It is interesting to notice that the network loss rate is smaller for NVI distribution utilities than for VI utilities (about 12% on average versus more than 16% on average). This higher network efficiency of NVI distribution utilities may be attributed to a different network structure. In order to take into account this possible effect, a network loss index weighted by the network length has been computed. Results for this index are similar

[9]In the empirical application, we will control for the fact that these services are not pure NVI production utilities by incorporating the ratio, water volume sold to another service to total water volume sold, as a determinant of the cost function.

Table 1: Network efficiency and vertical integration

| | | Network loss rate[(a)] | | | | Network loss index[(b)] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Obs. | Mean | Min | Max | Stdev. | Mean | Min | Max | Stdev. |
| Distribution Utilities | 60 | 0.123 | 0.000 | 0.453 | 0.118 | 0.251 | 0.000 | 0.854 | 0.225 |
| Integrated Utilities | 684 | 0.166 | 0.001 | 0.515 | 0.087 | 0.260 | 0.008 | 1.615 | 0.169 |

[(a)]: 1 − Volume sold/volume produced, in (%).
[(b)]: (volume produced − Volume sold)/network length, in (Mgals/Feet).

(even if less strong) to those obtained with the network loss rate. Distribution utilities tend to have less network losses than integrated services.

### 3.2 The data

Most of the data used for the econometric application have been provided by the Public Service Commission (PSC) of Wisconsin and come from the annual report filled each year by each water utility. The annual reports provide expenses by production stage (source of supply, pumping, water treatment, transmission and distribution). However, as we do not observe capital expenses by production stage, we estimate a variable cost function associated to each stage.[10]

The P&T or stage 1 output, $Y_1$, corresponds to the total water supply, that is the volume pumped from groundwater and/or withdrawn from surface water. $Y_1$ is measured in thousands of gallons (Mgal). The T&D or stage 2 output, $Y_2$, is the volume in Mgal sold by the water utility to final customers.

We consider 6 inputs that may enter the production process at the P&T stage and/or the T&D stage: labor, energy, chemicals, operation supplies and expenses, maintenance and water purchased $Y_1$. The unit price of labor at stage $s$, $W_{Ls}$ measured in US$ per hour, has been derived from the Occupational Employment Statistics (OES) Survey published each year by the US Bureau of Labor Statistics, Department of Labor.[11] The unit energy price, $w_E$, is measured in US$ per thousands of kilowatts. The unit energy price has been computed by dividing the

[10]Working on the electric network industry, Kwoka (2002) concludes that there are three main sources for economies of vertical integration. The first and the largest cost saving from integration is the reduction in the operating and maintenance costs of power supply. The second source identified by the author is lower operation costs of both transmission and distribution for integrated systems. Last, reduction of overhead expenses can be expected in an integrated system. As all these costs are operating expenses, we believe that considering a variable cost function with capital as a quasi-fixed input should not biased too much our measure of EVI.

[11]See Appendix A for more details about the computation of $w_{Ls}$.

energy expenses by the quantity of energy used. The price of water is obtained by dividing the water purchase expenses by $Y_1$. The operation supplies and expenses and the maintenance inputs correspond to various heterogeneous inputs. As it is difficult to express these inputs in terms of physical quantity, $w_{OSEs}$ and $w_{Ms}$ for $s = 1, 2$ have been obtained by dividing input expenses by the output of the corresponding stage, $Y_s$. Prices indexes are then defined in US$ per unit of output, see Appendix A for more details. For the chemicals input as we do not observe any physical measure of the quantity used, we proceed in the same way and compute a price index as a unit cost per thousand of gallons treated. Some descriptive statistics may be found in Table 2.

At the P&T stage the capital is represented by the actual capacity (in gallons per minute) of the pumping and power equipment and by the storage capacity (in thousands of gallons) of reservoirs. These two variables are respectively denoted by $CAP1_P$ and $CAP1_{WT}$. The physical measure of the capital used for the T&D stage is given by the length (in feet) of the distribution network, *Leng*. The number of users is finally used as a technical variable, $User$. We also consider the network return as a technical variable. For a vertically-integrated utility, the difference $Y_1 - Y_2$ mainly corresponds to the volume lost at the T&D stage but also to losses at the P&T stage and to the volume internally consumed by the water utility. Thus, the water network rate of return *Rt* is equal to $\frac{Y_2}{Y_1}$. For a non-vertically integrated distribution utility, the network rate of return corresponds to the ratio between the volume injected into the network and the volume sold to final users. The difference between these two volumes is equal to the transmission and distribution losses.

The descriptive statistics presented in Tables 1 and 2 reveal that the network efficiency and the size of water utilities (level of water supplied, network length or capital) vary with the type of vertical organization. This may suggest that the water utilities are not randomly selected into VI or NVI groups. Comparing the cost functions for VI and NVI utilities may require to deal with this potential selectivity bias. We investigate this issue in the next section.

### 3.3 The cost model

One underlying assumption of neoclassical cost functions is that firms minimize their cost only subject to an output constraint. But some other constraints (type of regulation implemented, rigidity in some input use) may also affect the cost minimization behavior of a firm. The resulting cost function may in such a case differ from the neoclassical one. As discussed previously, although the Wisconsin general principle of regulation for utilities is a rate of return framework, more than two-third of the water utilities are regulated by an interim price cap scheme, see

Table 2: Technological descriptive statistics

VI utilities: $N = 171$, $T = 4$

| Variable | Unit | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| $Y_2$ | Mgals | 419,299 | 632,330 | 15,173 | 4,290,751 |
| $w_{L1}$ | US$/Hour | 15.77 | 1.83 | 10.98 | 21.07 |
| $w_{OSE1}$ | US$/1,000 Mgals | 33.87 | 42.87 | 0.13 | 458.94 |
| $w_{M1}$ | US$/1,000 Mgals | 72.56 | 98.48 | 0.06 | 1,345.53 |
| $w_{E1}$ | US$ / Mkwh | 64.39 | 22.09 | 0.09 | 334.79 |
| $w_{C1}$ | US$/1,000 Mgals | 57.08 | 55.30 | 1.50 | 443.16 |
| $w_{L2}$ | US$/Hour | 10.79 | 1.28 | 8.28 | 15.36 |
| $w_{OSE2}$ | US$/1,000 Mgals | 183.39 | 139.55 | 6.47 | 1,111.37 |
| $w_{M2}$ | US$/1,000 Mgals | 197.05 | 140.06 | 0.99 | 868.75 |
| $Length$ | Feet | 252,186 | 275,575 | 17,435 | 1,731,558 |
| $CAP1_P$ | Gals/minute | 4,176 | 5,760 | 1 | 33,201 |
| $CAP1_{WT}$ | Gals | 2.40 | 2.11 | 1 | 21.07 |
| $User$ | - | 3,137 | 3,775 | 57 | 22,919 |
| $Rt$ | % | 0.83 | 0.09 | 0.48 | 1.00 |

NVI production utilities: $N = 17$, $T = 4$

| Variable | Unit | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| $Y_1$ | Mgals | 5,399,188 | 11,047,260 | 74,435 | 48,326,120 |
| $w_{L1}$ | US$/Hour | 16.31 | 1.78 | 10.98 | 20.54 |
| $w_{OSE1}$ | US$/1,000 Mgals | 18.83 | 24.34 | 0.06 | 109.06 |
| $w_{M1}$ | US$/1,000 Mgals | 65.74 | 88.14 | 0.52 | 631.02 |
| $w_{E1}$ | US$ / Mkwh | 53.05 | 16.04 | 32.80 | 147.19 |
| $w_{C1}$ | US$/1,000 Mgals | 65.09 | 75.56 | 5.45 | 269.35 |
| $CAP1_P$ | Gals/minute | 79,029 | 204,338 | 650 | 876,000 |
| $CAP1_{WT}$ | Gals | 10.79 | 18.86 | 0.30 | 79.00 |

NVI distribution utilities: $N = 15$, $T = 4$

| Variable | Unit | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| $Y_2$ | Mgals | 692,098 | 639,186 | 131,223 | 2,377,548 |
| $w_{Y_1}$ | US$/1,000 Mgals | 0.97 | 0.36 | 0.47 | 1.79 |
| $w_{L2}$ | US$/Hour | 13.24 | 1.08 | 9.88 | 14.99 |
| $w_{OS2}$ | US$/1,000 Mgals | 110.61 | 86.36 | 25.26 | 541.258 |
| $w_{M2}$ | US$/1,000 Mgals | 191.94 | 91.81 | 18.06 | 388.21 |
| $Length$ | Feet | 361,906 | 287,858 | 87,677 | 1,098,054 |
| $User$ | - | 5,188 | 5,083 | 1,174 | 19,569 |
| $Rt$ | % | 0.92 | 0.06 | 0.75 | 1.00 |

Aubert and Reynaud (2005). Hence, the cost minimization behavior of most water utilities in Wisconsin fits the neoclassical framework.

A functional form must be chosen in order to estimate the NVI and the VI cost functions. We use a translog approximation as it is convenient flexible functional form for computing substitution and network (density and scale) return measures, Christensen et al. (1973). The translog approximation of the cost function writes, in vector form:

$$\begin{aligned} \ln(VC) = {} & \alpha_0 + \sum_i \alpha_i \ln w_i + \alpha_y \ln Y \\ & + \frac{1}{2} \sum_i \sum_{i'} \alpha_{ii'} \ln w_i \ln w_{i'} + \frac{1}{2} \alpha_{yy} (\ln Y)^2 + \sum_i \alpha_{iy} \ln w_i \ln Y \\ & + \sum_k \alpha_k \ln Z_k, \end{aligned} \tag{15}$$

where $VC$ is $NT \times 1$ and represents the variable cost. $N$ is the total number of individuals and $T$ the number of periods (panel data). $w$ represents the vector of input prices with $i$ indexing each input, $Y$ the output and $Z$ a vector of all other ($k$) variables (capital and technical variables). Symmetry is imposed through the following restrictions: $\alpha_{ii'} = \alpha_{i'i}$. To ensure homogeneity of degree one in input prices, we divide the variable cost and the input prices by the price of a given input.[12] The system of input demand equations is derived according to Shephard's lemma as:

$$S_i = \alpha_i + \sum_{i'} \alpha_{ii'} \ln w_{i'} + \alpha_{iy} \ln Y, \tag{16}$$

where $S_i$, a $NT \times 1$ vector, represents the cost share of input $i$. The system made of the cost function (15) and the cost share equations (16) less one[13] is the cost model to be estimated.

# 4 Assessing the economies of vertical integration

## 4.1 Estimation methods for the cost model

The translog cost function along with its cost shares are estimated around the mean of observations (in logs). Hence, all right-hand side variables are normalized by their sample means. We add to each equation an error term independently and identically distributed. As standard in panel data econometrics, the error term is decomposed in an unobservable individual specific

[12] This is equivalent to imposing a set of restrictions on cost function parameters : $\sum_i \alpha_i = 1$, $\sum_i \alpha_{ii'} = \sum_{i'} \alpha_{ii'} = 0$, $\sum_i \alpha_{iy} = 0$.

[13] As the sum of cost shares is equal to unity, one of them is dropped to avoid singularity of the variance-covariance matrix of errors.

effect and a classical disturbance term. Two different methods have been used to estimate the cost model.

We use the Generalized Method of Moments (GMM, see Hansen, 1982) to estimate the parameters of the cost model. This method possesses several interesting advantages. First, it does neither require a precise definition of the model nor a specification of its probability distribution (as required by maximum likelihood methods, for instance). Moreover, as it will be discussed, some variables in the right-hand side term of the system may be considered as endogenous. Hence, following Cornwell, Schmidt, and Wyhowski (1992), the GMM estimator with panel data is based on orthogonality conditions and Instrumental Variables (IV). Finally, the GMM method allows to identify the parameters associated with variables that are not time variant (which is not possible using a Within method for instance).

For each equation of the cost model, we choose the instruments proposed by Hausman and Taylor (1981).[14] Using the moment conditions approximated by their empirical counterpart leads to the GMM estimator of the system. The variance-covariance matrix is computed by first estimating the parameter vector with a unit variance-covariance matrix for error terms (IV method), and then minimizing the GMM criterion where the error terms are replaced by their first-step IV residual estimates. This produces heteroskedasticity-consistent parameter estimates. The system GMM estimator with panel data is:[15]

$$\hat{\beta}_{SGMM} = (R'A\hat{\Phi}^{-1}A'R)^{-1}R'A\hat{\Phi}^{-1}A'Y, \tag{17}$$

where $Y$ is the $(MHT \times 1)$ vector of dependent variables, $R$ is the $MHT \times K$ matrix of regressors, $A$ is a $MHT \times L$ matrix of valid instruments, with $M$ denoting the number of equations in the cost system (cost and share equations), $H$ the number of utilities, $T$ the number of periods. Moreover, $\widehat{\Phi}$ is the variance-covariance matrix estimated from the IV residuals.

However, the GMM estimator possesses good properties only for large samples. As, we have a limited number of observations for NVI production and distribution utilities, we use another estimation method, based on the Seemingly Unrelated Regression approach (SUR, see Zellner, 1962). Considering the estimation of a set of SUR equations with panel data, we apply a fixed-effects method consisting in transforming all the variables of the system by the Within operator (variables with a tilde in the equation below). After a (first-step) OLS estimation on the

[14]There exist even more efficient IV procedures, see Amemiya and MaCurdy (1986), and Breusch, Mizon, and Schmidt (1989). However, given the size of our sample, the number of overidentifying restrictions is already important and adding more instruments can lead to bias estimates. The choice of instruments is discussed in the following paragraphs.

[15]See Garcia and Reynaud (2004) for a more detailed description of the method.

transformed system, we replace error terms by Within-type residuals (see Baltagi, 1995, p.103), so that the Within-SUR estimator of the cost model writes:

$$\hat{\beta}_{WSUR} = [\tilde{R}'(\hat{\Sigma}_{\varepsilon}^{-1} \otimes I_{HT})\tilde{R}]^{-1}\tilde{R}'(\hat{\Sigma}_{\varepsilon}^{-1} \otimes I_{HT})\tilde{Y}, \quad (18)$$

where $\hat{\Sigma}_{\varepsilon}$ is the variance-covariance matrix estimated from the Within residuals.

## 4.2 Cost estimates results

### 4.2.1 Cost estimation and sample selection problem

The cost functions for vertically and non vertically integrated firms have been separately estimated. As there are some local factors that may explain the integration choice, any direct comparison of the two cost functions may suffer from a selection bias. In order to test whether this problem is significant or not, we explicit model the vertical integration choice using a probit model. As potential determinant of the VI/NVI choice, we include several technical variables related to network and production characteristics of the water services. Table 3 presents the estimation results of the selection equation.

Table 3: Probit selection equation for the VI/NVI choice

| Variable | Description | Coef. | Std. Error | t-stat |
|---|---|---|---|---|
| Constant | | 0.7761 | 0.2699 | 2.8757 |
| *Depth* | Average pumping depth for groundwater (in meters) | 0.0000 | 0.0003 | 0.1030 |
| *Dist* | Average transportation distance for surface water (in meters) | 0.0001 | 0.0001 | 0.5272 |
| *GW* | Dummy variable equal to 1 if all water comes from groundwater | 0.2009 | 0.0593 | 3.3896 |
| *SW* | Dummy variable equal to 1 if all water comes from surface water | 0.0442 | 0.3859 | 0.1546 |
| *Fluo* | Dummy variable equal to 1 if water is fluoridated | 0.2162 | 0.2698 | 0.8013 |
| *Length* | Total length of the water network (in km) | -0.0005 | 0.0017 | -0.3079 |
| *Met* | Number of meters | -0.0003 | 0.0005 | -0.5627 |
| *User* | Number of users | 0.0002 | 0.0005 | 0.4132 |

The pseudo R-squared of McFadden is 0.23 and the percentage of correctly predicted choices is 87%. Moreover, only one variable is statistically significant, $GW$. The low predictive power of the VI/NVI choice model indicates that the observable characteristics badly explain this choice. This means either that the vertical integration choice is random or that we do not have the correct determinants of this choice in our database. As pointed out by Heckman (1979), computing the inverse of the Mills ratio for each observation from the Probit equation and using it as a regressor in the cost function allows to consistently estimate all the parameters of the model. This procedure is called "Heckit" in Table C.1. A simple test of the null hypothesis of no selection bias can be conducted by checking if the inverse of the Mill ratio terms is significant or not in the cost model. As shown in Table C.1, the coefficient is not statistically significant (a value of 0.0113 for a standard error of 0.1644), hence we do not reject the null hypothesis of no selection bias.[16] Moreover, the differences between the GMM and the Heckit estimates are small, see Table C.1.

#### 4.2.2 Vertically-integrated water utilities

In order to use the GMM method, it is necessary to make some exogeneity assumptions for constructing the orthogonality conditions associated to the GMM criterion. There are several sources of potential endogeneity in our system of equations. First, the exogeneity of output levels is quite doubtful in practice. As shown in Table 1, the network loss rate significantly differs according to the vertical structure of the water service. Garcia and Thomas (2001), working on a sample of French water utilities, have shown that there exists a trade-off between water network efficiency and costs of network repair. Injecting higher water volumes into the distribution network (and thus having higher losses) may be in some cases a cost effective alternative to network maintenance costs. For these reasons, the water output and the water network rate of return may be endogenous in our model. Second, as some input unit prices are computed as a function of the water output, they may be endogenous if the latter is. We will test the endogeneity of these variables using a Hansen test.

The Hausman-Taylor's instruments have been used in the estimation process. The matrix of instruments is made of all time-varying regressors centered by the Within transformation and all time-varying regressors but the endogenous ones cited above and their associated cross-products[17]. The matrix of instruments also contains all time-invariant variables supposed to be exogenous. There are 50 parameters to be estimated with 88 instruments for the variable cost function of VI utilities. These 50 parameters are presented in Table C.1 in Appendix C. We have checked for the validity of the moment conditions with a Hansen test. The test statistic is equal to 60.25 with 70 degrees of freedom[18]. With an associated p-value equal to 0.7906, the

[16] In such a case, the unadjusted standard error for the Mills ratio presented in Table C.1 is valid, see Wooldridge (2002).

[17] Using Hansen tests, we finally do not reject the exogeneity of input prices.

model specification and the choice of instruments are not rejected at the 5 percent level.

We have also reported in Table C.1 an estimation of the cost model using the iterated SURE method. The value of coefficients are similar.

Using Likelihood ratio tests, we have evaluated our cost specification. More specifically, we have tested the homotheticity of the production, the unitary substitution elasticity and the possibility of a Cobb-Douglas technology. All null hypotheses are rejected at the 5 percent level. Moreover, the cost monotonicity and concavity in input prices is satisfying since the estimated cost shares are positive for a vast majority of observations[19] and since the $\alpha_{ii'}$ matrix (corresponding to the quadratic terms related to input prices) is semi-definite negative.

### 4.2.3 Non-vertically integrated water utilities

As the number of observations is limited to 68 for NVI production utilities and to 60 for NVI distribution utilities, the cost functions are estimated using a Within-SURE method detailed above. Notice that since the fixed term vanishes after the within transformation, the problem of correlation with regressors disappears. However, it is not possible to identify parameters of time-invariant regressors[20] and the Within-SUR estimator is not efficient. In order to increase efficiency of the Within-SUR estimator, we use an iterative procedure *à la Zellner*.[21] Results of these estimations are presented in Table C.2 and Table C.3.[22]

Last, we have realized some specification tests for NVI production and distribution utilities. Only the homotheticity hypothesis (i.e. 4 restrictions) for the NVI distribution services has not been rejected at the 5 percent level. The value of the statistic is equal to 3.367 and the p-value of the test is 0.498. We have imposed this constraint on the cost function which reduces the number of parameters to be estimated. Finally, the properties of monotonicity and global concavity are verified ex-post.

[18]The cost system contains 113 parameters for 183 instruments.

[19]Only a very few estimated cost shares are negative due to the fact that some observed shares are very close to 0.

[20]Only two regressors (i.e. the capital variables) in the NVI production cost model do not vary over time. The impact on EVI results is very limited since these variables are not significant in the VI cost function.

[21]The estimated variance covariance matrix obtained at the first GLS step is used to iteratively update the estimated parameter vector. This iterative procedure ends once the log-likehood has converged so that maximum likelihood estimates can be obtained.

[22]In order to check that firm's technological characteristics are not the same whether they are integrated or not, we have separately estimated the cost function for the production and the distribution stages using the VI utilities (684 observations). Then we have compared the estimated cost parameters with those obtained using the NVI production (68 observations) and distribution (60 observations) services. All these estimations are available from the authors upon request. The estimated coefficients appear to be significantly different both for the production and the distribution stages. This result tends to confirm that the technological characteristics of the water utilities differ according to the vertical structure (VI versus NVI). In such a case, estimating a single cost function on the whole dataset would clearly result in a misspecification of the econometric model.

### 4.3 Analysis of cost estimate

From the cost function estimates, we have computed the average and marginal costs for the VI utilities and for the NVI utilities. We report in Table 4 these estimates for the average utility (at the sample mean of the variables).

Table 4: Estimates of marginal and average costs (in US$ per Mgals) for the average utility

| | | Estimate | Standard Error |
|---|---|---|---|
| NVI Production utility | MVC | 0.2275 | 0.0164 |
| | AVC | 0.2247 | 0.0299 |
| NVI Distribution utility | MVC | 1.2906 | 0.0778 |
| | AVC | 1.1800 | 0.0221 |
| VI utility | MVC | 0.7589 | 0.0594 |
| | AVC | 1.2021 | 0.0448 |

Notes: MVC for marginal variable cost, AVC for average variable cost.

The results on marginal costs give a good idea of the cost differential between the two stages. In particular, for the average service the sum of marginal costs at each stage (in the NVI structure) is significantly greater than the overall marginal cost (in the VI structure).[23] But these two figures are in fact not directly comparable since the NVI marginal cost include the water purchase expenses of the NVI distribution utility.

When we compare the MVC and AVC, the greater value of the AVC for the average VI utility seems to indicate the existence of economies of scale. The small difference between MVC and AVC for the NVI Utilities prompts us to be reserved on the nature of returns to scale. One possible explanation is that the size on the average VI utility (both measured in term of number of customers, water sold to final users, length of the network) is significantly smaller[24] than the size of the average NVI utility. The VI utilities may not have exhausted all economies of scale. It is possible that imposing the average VI utility to produce higher level of water will not result in the presence of scale economies.

Following Caves et al. (1984), we now more formally consider the way the number of customers, the volume of production and the size of capital may affect the variable cost function. Considering both the number of customers and capital allows us to distinguish between returns

[23] The null hypothesis of a sum of NVI marginal costs equal to the VI marginal cost is rejected at a 1% level of significance. The Student's t-statistic is equal to 4.43.

[24] A simple unilateral test on the means allows for checking this statement.

to density (with respect to production) and returns to scale, see Garcia and Thomas (2001) for more details.[25] All scale measures are computed for the average utility and are presented in Table 5.

Table 5: Estimates of network returns for the average utility

| | | Estimate | Standard Error |
|---|---|---|---|
| NVI Production utility | $RTS_{SR}$ | 0.9875 | 0.0737 |
| NVI Distribution utility | $RTD_{SR}$ | 0.9143 | 0.0584 |
| | $RTS_{SR}$ | 1.1852 | 0.1404 |
| | $RTS_{LR}$ | 1.1913 | 0.1014 |
| VI utility | $RTD_{SR}$ | 1.5839 | 0.1155 |
| | $RTS_{SR}$ | 1.4029 | 0.1224 |
| | $RTS_{LR}$ | 1.1668 | 0.0879 |

Notes: $RTD$ for returns to density, $RTS$ for returns to scale.
SR and LR means respectively short run and long run.

First, we find significant and important short run returns to density for the average VI utilities. This means that an increase in the demand per user will result in a decrease of the average cost. Second, there are significant (at a 1% confidence level) short run returns to scale for the average VI water utility. This means in such a case that the water network is not overloaded in terms of customer connections. On the short run, the network may accommodate more customers at a lower cost. Still considering the short run returns to scale, our estimates suggest that the average NVI distribution utility is characterized by constant returns.

Concerning the average NVI production utility, we only report results on short run returns to scale since the SURE method does not allow to identify coefficients related to capital variables. They are not significantly different from 1 at 5%. The constant returns to scale for the average NVI production utility indicate that the production/generation stage could be considered as

[25] The short run returns to density ($RTD_{SR}$) measure the cost savings that result from an increase in production, holding constant both the number of customers and the size of capital. $RTD_{SR}$ is equal to $1/\varepsilon_Y$ where $\varepsilon_Y$ denotes the cost elasticity with respect to output. The short run returns to scale ($RTS_{SR}$) measure the cost savings that result from an increase in production to satisfy the demand from new customers (here the demand per customer is constant) for a given level of capital. $RTS_{SR}$ is computed as $1/(\varepsilon_Y + \varepsilon_U)$, where $\varepsilon_C$ is the cost elasticity with respect to the number of customers. The long run returns to scale ($RTS_{LR}$) measure the proportional increase of water volume and number of users made possible by a proportional increase of all inputs (including capital). Denoting by $\varepsilon_K$ the cost elasticity with respect to capital $K$, the long run returns to scale are defined as $(1 - \varepsilon_K)/(\varepsilon_Y + \varepsilon_U)$. Returns are increasing , constant or decreasing if the associated index ($RTD_{SR}$, $RTS_{SR}$, $RTS_{LR}$) is greater than, equal to or less than 1, respectively. Notice that for NVI production utilities, returns to density and to scale cannot be differentiated because there is no distribution network and the only customer is the NVI distribution service.

potentially competitive. However, the high standard error associated to $RTS$ for the average NVI production utility indicates that this result crucially depends on the size of the service. Indeed, the parameter related to the square of volume (in logarithm) in the cost function is significantly positive, see Table C.2. This means that the returns to scale decrease with the water production. The smallest NVI production utilities of our sample are in fact characterized by economies of scale.

Last, the long run returns to scale for the average NVI distribution utilities are significantly greater than 1 (at a 10% level). On average the water utility has not exploited the economies of scale, so that the size of the network is not efficient. Last, we consider the VI services. At the sample mean, $RTS_{LR}$ is significantly different from 1 at a 10% level. The average VI utility is characterized by increasing long run returns to scale. An increase in the service size (i.e. production, customers and network) will result in a decrease of the average cost.

## 4.4 Results on vertical integration

### 4.4.1 Global economies of vertical integration

In order to estimate GVI, we simulate the cost for different levels of final output and different prices for the intermediate good, both for a VI utility and for a NVI structure. More precisely, we proceed in the following way.

(1) We compute the estimated total cost for a VI utility assigned to sold to final users different water quantities $\{Y_{2_1}, \ldots, Y_{2_K}\}$ uniformly distributed over a relevant range of values.

(2) We compute the estimated cost for a NVI distribution utility, assigned to sold to final users the same quantities $\{Y_{2_1}, \ldots, Y_{2_K}\}$. For each quantity of final output $Y_{2_k}$, we consider $L$ possible prices of the intermediate good $\{w_{Y_{11}}, \ldots, w_{Y_{1L}}\}$. This results in $K \times L$ estimates of the cost of the NVI distribution utility and $K \times L$ derived demands in water, $Y_1^{nvi}(Y_{2k}, w_{Y_{1l}})$.

(3) We then compute the estimated cost for a NVI production utility assigned to produce the quantities $Y_1^{nvi}(Y_{2k}, w_{Y_{1l}})$.

(4) We compute the total cost of production of the NVI structure, net of the water purchase cost for the intermediate good, for each $(Y_{2_k}, w_{Y_{1l}}), \ldots, k = 1, \ldots K$ and $l = 1, \ldots L$.

(5) We compute the global economies of vertical integration $GVI$, defined by equation (7), for each $(Y_{2_k}, w_{Y_{1l}}), \ldots, k = 1, \ldots K$ and $l = 1, \ldots L$.

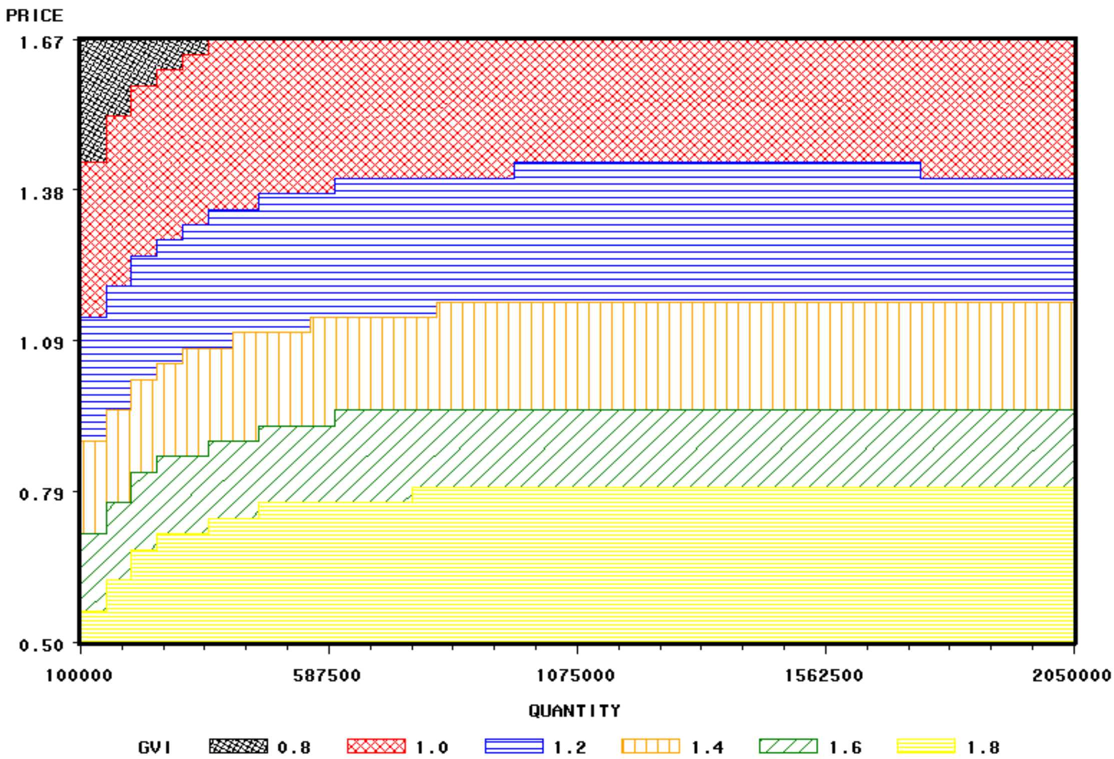


Figure 1: Global Economies of Vertical Integration

Notice that the capital variables are adjusted to each level of production. A statistical relationship between the level of production and the capital infrastructure (pumping and power equipment, storage capacity, network length) is first estimated for each class of utility. When computing the cost associated each production level, the capital variable is adjusted according to the estimated statistical relationship. As the cost of a non-vertically integrated structure depends on the price for intermediary water, GVI are given for different levels of the final output but also for different prices of the intermediary good, see Figure 1.

First, in the $(w_{Y_1} \times Y_2)$ space we both observe zones characterized by global economies of vertical integration $(GVI \leq 1)$ and by diseconomies $(GVI > 1)$. This means that there are zones where a VI structure can produce water at a lower cost than a NVI structure, and other where a NVI structure is more cost effective. We find that there are global economies of vertical integration for small services (i.e. for utilities characterized by a small volume of water sold to final users) and for a high intermediary water price (high intermediary prices create important distortions in terms of input allocation). For small utilities, integration involves significant technological and transactional economies. This suggests that undue fragmentation can lead to a misallocation of resources (fragmentation of responsibilities for planning, investment, operations and maintenance may lead to a loss of efficiency because decision-makers do not have an appropriate level of control over decisions and actions that affect their efficiency). It is also possible that the market power on the intermediary good does not favor small NVI distribution utilities. Hence, small utilities may find profitable to integrate vertically to reduce misallocations due to the upstream mark-up.

Second, for a given price of the intermediate water, the lower is the final output, the higher are global economies of vertical integration. One possible explanation is that, for small water utilities, the specialization of inputs across stages is quite limited because the production process is more simple. Hence, interdependences across stages are higher for small utilities than for large ones, which means that a VI structure is more cost effective in that case. For a given level of the final output, the higher is the intermediate water price, the higher are global economies of vertical integration. A high price of the intermediate water good means a high mark-up on the upstream market. This creates important distortions in terms of input allocation at the downstream stage. In such a case being integrated would result in important cost savings.

Third, it is interesting to see where the average Wisconsin VI and NVI distribution utilities are located in the $(w_{Y_1} \times Y_2)$ space. For the average NVI distribution utility, the water price is 0.97 US$ per Mgals and the final volume sold is 692,098 Mgals. For these values the GVI index is equal to 1.45. There are global diseconomies of vertical integration and a NVI structure is a cost effective solution. Nest, we consider the average VI service. The water volume sold by the average VI utility to final users is equal to 419,299 Mgals. For such a level of water, we find global economies of vertical integration ($GVI < 1$) only for an intermediary water price greater than 1.49 US$ per Mgals. It follows that for a lower water price, vertical separation would result, in such a case, in a cost saving.

Last, our findings are significantly different from what has been previously found by Kaserman and Mayo (1991), Kwoka (2002) and Nemoto and Goto (2004) working on the electric utility industry. They both found that vertical integration results in cost saving for almost all production levels, at the exception of the smallest ones. Kwoka (2002) reports for example that at the mean level for distribution and generation outputs, the efficiency gain from integration represents 42 percent of the cost. We do also find global economies of vertical integration but only for small levels of the final output (or for prohibitive intermediate water price). One possible explanation is that the need for coordination between generation, transportation and distribution is much more important in the electric industry than in the water sector. It is for example well-know that a real-time management of power flows is required in order to guarantee energy balance in the network and to prevent failure of the system. In the same vein, as electricity flows across the network in accordance with the laws of physics, it cannot be controlled through a command and control system. This may impose high externality costs in case of non-vertically integrated systems. The need for such a coordination between the different stages is less stringent for a water network than for an electric system.

Our results also differ from those obtained for two other natural resource industries, namely the gas and the oil sectors. Oil and gas companies are usually active in several sectors of activity including exploration, production, transport, distribution. But, an important motivation for the vertical integration of oil an gas companies is to mitigate the impact of intermediate good price cycles and, hence to reduce profit volatility, Perruchet and Cueille (1991). Such an effect is not present in the water network industry as the water price does not strongly fluctuate. Before deriving the economic implications of these results, we still need to isolate the technological economies of vertical integration from the global ones.

#### 4.4.2 Technological economies of vertical integration

We now evaluate the level of TVI. We proceed in the following way.

(1) We compute the estimated marginal cost of production for a non-vertically integrated producer utility for $K$ levels of the final output $Y_1$, $\{Y_{1_1}, \ldots, Y_{1_K}\}$.

(2) Given that volumes $\{Y_{1_1}, \ldots, Y_{1_K}\}$ are sold by the non-vertically integrated producer to the non-vertically integrated retailer utility at the marginal cost, we compute the associated final output $\{Y_{2_1}, \ldots, Y_{2_K}\}$ and the associated costs.

(3) We compute the production cost of a vertically-integrated utility assigned to sold to final users the different quantities $\{Y_{2_1}, \ldots, Y_{2_K}\}$.

(4) We compute TVI for $\{Y_{2_1}, \ldots, Y_{2_K}\}$ defined by equation (14).

In Figure 2, we have plotted TVI, defined by equation (14), as a function of the final output. Remember that TVI $\leq 1$ means that there are technological economies of vertical integration. First, there are technological economies of vertical integration only for small levels of final output (for a final output a little bit higher than 100,000 Mgals). This means that, if marginal cost pricing is implemented on the upstream market, a vertically integrated structure is a cost effective solution only if the utility is small enough. The technological economies of vertical integration

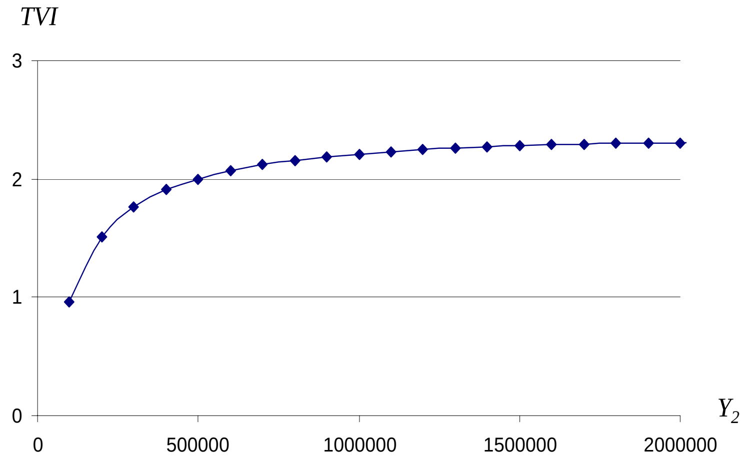


Figure 2: Technological Economies of Vertical Integration

for small services can also be understood by considering the characteristics of their production and distribution costs. In case of a small size, the distribution service can capture the economies of scale at the production stage by integrating it. The aggregation of the average production and distribution cost functions allows to produce at a level with an overall average cost closer to its minimum.

From this Figure, the vertical organization of Wisconsin water utilities can be discussed. First, for 43 VI water utilities (25% of the sample), the volume of water sold to final users is smaller than 100,000 Mgals. As these services belong to a zone characterized by technological economies of vertical integration, their vertical organization is cost efficient. Notice however that, for the average VI Wisconsin water utility, the TVI index is equal to 1.94: if the regulator is able to enforce marginal cost pricing, vertical separation may result in important efficiency gains. Second, for all NVI distribution utilities, the volume of water sold to final user is greater than 100,000 Mgals. For those services, the vertical separation is a cost effective solution even if marginal cost pricing is enforced on the upstream market. To conclude, the technological economies of vertical integrations help understanding why the average VI utility in the Wisconsin is smaller (both in terms of water delivery or customer number) than the NVI distribution utility.

These results are difficult to compare with the economies of vertical integration reported by Kwoka (2002) and by Kaserman and Mayo (1991) for the electric network industry because these papers do not distinguish the global economies of vertical integration from the technological ones. However given the high level of global economies reported in these papers, it is likely that applying our framework would result in finding technological economies of vertical integration for large electric utilities, an opposite conclusion to what we find for water utilities. We believe that specialization of inputs by production stage (or asset specialization) is much more important than coordination across stages for large water utilities than for large electric utilities.[26] This may explain why large water utilities are characterized by important technical diseconomies of vertical integration whereas large electric utilities are more likely to present economies. The higher network efficiency of NVI distribution utilities (see Table 1) may be viewed as a result of the stage specialization.

### 4.4.3 Discussion

These results have some important policy implications in terms of the water industry organization. But first, it is important to remember that a specific characteristic of the water sector is the regulation of the final market by a public authority. In particular the price of water delivered to final consumers is often, at least partially, under the control of the regulatory authority. This is clearly the case in the Wisconsin where all water utilities are regulated by the Public Service Commission. The general principle of regulation for Wisconsin water utilities is that 'All investors must receive a fair return on their investments [...] the PSC is required by law to provide an opportunity for the utility to earn a reasonable return to ensure adequate service'. By implementing this rate of return framework, the Public Service Commission of Wisconsin monitor the price paid by final users.[27] It follows that, in terms of social welfare, what really matters is the cost efficiency.[28]

Based on efficiency considerations there is no clear answer to the debate about separation of production & treatment and transportation & distribution stages in the water industry. If the public authority cannot enforce marginal cost pricing on the upstream market, the cost efficient

[26] A good example of coordination requirement between production and distribution in the electric industry is power pools. Power pools are agreements among independent utilities aiming at coordinating certain activities (joint scheduling of shutdowns for instance). To our knowledge, there are no similar agreements in the water sector. The main reason for connecting to water networks is to secure water sources. Technological economies of vertical integration from a better coordination of stages are likely small in the water industry.

[27] The PSC usually monitors water utility prices through a procedure called the simplified rate case which combines some aspects of a rate-of-return regulation with an upper bound for the water price increase. Moreover, a complete financial and a technical audit of the water utility can be implemented by the PSC staff.

[28] It is clear that if the final market was not regulated, the vertical structure maximizing the social welfare may not coincide with the one minimizing the production cost. Indeed, due to possible technical efficiencies, the market power might be larger in the case of an integrated firm than in the case of two separated firms. Vertical separation may be preferred in that case.

vertical structure is derived from the GVI index. Vertical integration should then be promoted only for the smallest size services. For instance, with a water price on the intermediate market around 1.3 US$ per Mgals, a vertical integration is a cost effective solution only for a final water volume lower than 150,000 Mgals per year. If the public authority can enforce marginal cost pricing on the upstream market then the optimal vertical structure is derived from the TVI index. Here, again, the vertical integration is a cost effective solution only for the smallest size services (for an annual volume of water sold to final users lower than 100,000 Mgals). It is clear that an important task of the regulator will be to enforce marginal cost pricing in such a case. It is likely that, given the limited number of production utilities, such a market will suffer from a lack of competition. The additional regulation cost should of course be taken into account to determine the optimal vertical structure of the water industry.

## 5 Conclusion

An important task of competition policy authorities is to isolate the natural monopoly activities of network industries from potentially competitive ones. The underlying objective is often to prevent the firms entrusted with such activities from extending their monopoly power on competitive segments. In network industries characterized by multi-stage production processes, achieving this objective requires to analyze the cost structure of vertically and non-vertically integrated firms. The question of vertical integration addressed in this paper is not a simple issue as many factors need to be carefully analyzed. These factors include the technical, technological and economic constraints to separation. The potential benefits of vertical separation have to be carefully balanced against the loss of scope and scale economies, the costs of sector restructuring, and the possible loss of externality internalization. If these costs (in particular, economies of scope) are significant, there may be a case for the continuation of a vertically-integrated monopoly. If not, a vertical separation could be desirable. If parts of an industry must remain integrated, vertical conduct regulation or measures of partial vertical separation will be needed to establish conditions for effective competition.

In this context, identifying sources of economies of vertical integration is crucial. By estimating separately the cost function of vertically integrated and non-vertically integrated structures, we have proposed a framework that allows to distinguish the technological economies of vertical integration from those resulting from inefficient input allocation due to upstream market imperfections. These issues related to the vertical integration of water utilities have been investigated by estimating the production and distribution cost function for some North American water utilities. By separately considering the production and the distribution stages, we have shown that there are disintegration of these two stages may lead to cost savings (at the exception of the smallest services). In addition, as the returns to scale at the production stage are shown to be constant, introducing competition could have some welfare improving effects.

Focusing only on global economies of vertical integration to assess the optimal structure of an industry can be misleading if those economies mainly result from cost distortions due to market imperfections. We have shown that there are no evidence of technological economies of vertical integration (at least for large utilities) between the production and distribution stages. This means that if marginal cost pricing can be enforced on the upstream market for the intermediary good, vertically disintegrated utilities should be promoted. This result for the water network industry appears to be different from what has been previously found for the electric industry, see Kaserman and Mayo (1991), Kwoka (2002) and Nemoto and Goto (2004) among others. We believe that for the water network industry, the specialization of inputs by production stage or the asset specialization may generate more cost savings than the coordination across stages; a situation that may not hold for electric utilities. This may explain why most of the water utilities in our sample are characterized by important technological diseconomies of vertical integration.

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# A Computation of input prices

**Labor** The technical and financial annual reports give labor expenses at 5 steps of the production process: Source of supply (SS), Pumping (P), Treatment (T1), Transmission (T2), Customers account (CA) from 1997 to 2000. In order to estimate the two-stage cost function, we need to define for each water utility and at the P&T and T&D stages the unit cost of labor.

The unit cost of labor is derived from the Occupational Employment Statistics (OES) Survey published each year by the US Bureau of Labor Statistics, Department of Labor. This survey gives the mean hourly wage for the 11 Metropolitan Areas (MA) of the Wisconsin and for various occupations. We have matched each water utility with the corresponding Metropolitan Area. Then, we have matched each step (SS, P,T1, T2 and CA) with the OES corresponding occupation.

For each water utility, the P&T unit cost of labor is then the sum of the unit labor costs for SS, P and T1 weighted by the expenses for these three categories. The T&D labor cost corresponds to the sum of the unit labor costs for T2 and CA weighted by the expenses for these two categories. Both labor prices $w_{Ls}$ $s = 1, 2$ are in $US\$/hours$.

**Energy and Purchased water** The price of energy $w_E$ is defined as the expenses for fuel or power purchased divided by the quantity of energy used in thousands of kilowatts per hour ($MkWh$). The unit price of energy is thus defined in US$ per $MkWh$. The price of purchased water $w_{Y_1}$ is defined as the ratio of purchased water expenses to the quantity of water purchased in thousands of gallons (Mgals). The unit price for the water input is in US$ per Mgals.

**Operation supplies and expenses, Maintenance and Chemical** The main difficulty is that expenses associated to these inputs are very heterogeneous. In order to construct a price index associated to each input, $w_{OESs}$ and $w_{Ms}$ for $s = 1, 2$, we have divided input expenses by the output of the stage considered, $Y_s$ in millions of gallons (MMgals). Price indexes are defined in US$ per unit of output. The implicit assumption is that the unobserved quantity of input increases proportionally with the level of output. For the chemical input we do not observe any physical measure of the quantity used by the water utility. A price index is construct by dividing expenses for chemical by $Y_1$ in MMgals. The price of chemical is defined in US$ per MMgals.

# B Input shares and cost descriptive statistics

Table B.1: Cost descriptive statistics for VI utilities, 684 observations

| Variable | Mean | Min. | Max. | Stdev. |
|---|---|---|---|---|
| $VC$ | 444,373 | 31,191 | 3,740,468 | 512,805 |
| $S_{L1}$ | 0.1025 | 0.000 | 0.344 | 0.0758 |
| $S_{OSE1}$ | 0.0248 | 0.000 | 0.300 | 0.0327 |
| $S_{M1}$ | 0.0575 | 0.000 | 0.519 | 0.0587 |
| $S_{E1}$ | 0.1115 | 0.000 | 0.583 | 0.0575 |
| $S_{C1}$ | 0.0440 | 0.000 | 0.256 | 0.0409 |
| $S_{L2}$ | 0.3142 | 0.027 | 0.660 | 0.1123 |
| $S_{OSE2}$ | 0.1792 | 0.030 | 0.525 | 0.0746 |
| $S_{M2}$ | 0.1663 | 0.002 | 0.594 | 0.0863 |

Table B.2: Cost descriptive statistics for NVI production utilities, 68 observations

| Variable | Mean | Min. | Max. | Stdev. |
|---|---|---|---|---|
| $VC$ | 1,409,931 | 27,144 | 11,984,756 | 2,683,740 |
| $S_{L1}$ | 0.3203 | 0.110 | 0.578 | 0.1388 |
| $S_{OSE1}$ | 0.0538 | 0.001 | 0.206 | 0.0485 |
| $S_{M1}$ | 0.1710 | 0.003 | 0.468 | 0.0909 |
| $S_{E1}$ | 0.3090 | 0.072 | 0.629 | 0.1342 |
| $S_{C1}$ | 0.1459 | 0.000 | 0.395 | 0.1078 |

Table B.3: Cost descriptive statistics for NVI distribution utilities, 60 observations

| Variable | Mean | Min. | Max. | Stdev |
|---|---|---|---|---|
| $VC$ | 1,079,309 | 347,704 | 3,595,949 | 920,102 |
| $S_{Y_1}$ | 0.6194 | 0.397 | 0.798 | 0.0908 |
| $S_{L2}$ | 0.1435 | 0.060 | 0.348 | 0.0584 |
| $S_{OSE2}$ | 0.1024 | 0.032 | 0.280 | 0.0504 |
| $S_{M2}$ | 0.1347 | 0.008 | 0.301 | 0.0644 |

# C Cost functions estimates

Table C.1: Cost function for VI utilities

| | HECKIT | | GMM | | Iterated SURE | |
|---|---|---|---|---|---|---|
| Variable (in log) | Coef. | Std. Error | Coef. | Std. Error | Coef. | Std. Error |
| Constant | 9.7273 | 0.0400 | 9.7213 | 0.0373 | – | – |
| $Y_2$ | 0.6315 | 0.0461 | 0.6313 | 0.0461 | 0.6840 | 0.0377 |
| $w_{OSE1}$ | 0.0249 | 0.0032 | 0.0248 | 0.0032 | 0.0305 | 0.0042 |
| $w_{M1}$ | 0.0604 | 0.0037 | 0.0603 | 0.0037 | 0.0681 | 0.0030 |
| $w_{E1}$ | 0.0634 | 0.0165 | 0.0632 | 0.0165 | 0.0671 | 0.0066 |
| $w_{C1}$ | 0.0706 | 0.0153 | 0.0707 | 0.0151 | 0.0565 | 0.0077 |
| $w_{L2}$ | 0.3118 | 0.0127 | 0.3118 | 0.0127 | 0.3540 | 0.0260 |
| $w_{OSE2}$ | 0.1795 | 0.0070 | 0.1794 | 0.0071 | 0.1681 | 0.0099 |
| $w_{M2}$ | 0.1683 | 0.0052 | 0.1684 | 0.0052 | 0.1818 | 0.0049 |
| $Y_2 \cdot Y_2$ | 0.0001 | 0.0479 | 0.0145 | 0.0484 | 0.0887 | 0.0342 |
| $w_{OSE1} \cdot w_{OSE1}$ | 0.0145 | 0.0017 | 0.0145 | 0.0017 | 0.0138 | 0.0008 |
| $w_{M1} \cdot w_{M1}$ | 0.0358 | 0.0025 | 0.0358 | 0.0025 | 0.0358 | 0.0011 |
| $w_{E1} \cdot w_{E1}$ | 0.0262 | 0.0039 | 0.0263 | 0.0039 | 0.0296 | 0.0014 |
| $w_{C1} \cdot w_{C1}$ | 0.0298 | 0.0033 | 0.0297 | 0.0033 | 0.0298 | 0.0012 |
| $w_{L2} \cdot w_{L2}$ | 0.0660 | 0.0333 | 0.0656 | 0.0332 | 0.0804 | 0.0122 |
| $w_{OSE2} \cdot w_{OSE2}$ | 0.1016 | 0.0083 | 0.1013 | 0.0086 | 0.1023 | 0.0030 |
| $w_{M2} \cdot w_{M2}$ | 0.0898 | 0.0053 | 0.0897 | 0.0053 | 0.1009 | 0.0020 |
| $w_{OSE1} \cdot w_{M1}$ | 0.0000 | 0.0012 | 0.0000 | 0.0012 | 0.0003 | 0.0006 |
| $w_{OSE1} \cdot w_{E1}$ | -0.0002 | 0.0018 | -0.0002 | 0.0018 | -0.0019 | 0.0008 |
| $w_{OSE1} \cdot w_{C1}$ | 0.0000 | 0.0015 | 0.0000 | 0.0015 | -0.0007 | 0.0006 |
| $w_{OSE1} \cdot w_{L2}$ | -0.0042 | 0.0044 | -0.0042 | 0.0044 | -0.0003 | 0.0020 |
| $w_{OSE1} \cdot w_{OSE2}$ | -0.0044 | 0.0026 | -0.0045 | 0.0026 | -0.0056 | 0.0011 |
| $w_{OSE1} \cdot w_{M2}$ | -0.0031 | 0.0024 | -0.0029 | 0.0024 | -0.0028 | 0.0009 |
| $w_{M1} \cdot w_{E1}$ | -0.0045 | 0.0016 | -0.0045 | 0.0016 | -0.0040 | 0.0006 |
| $w_{M1} \cdot w_{C1}$ | -0.0017 | 0.0012 | -0.0017 | 0.0012 | -0.0023 | 0.0004 |
| $w_{M1} \cdot w_{L2}$ | -0.0142 | 0.0037 | -0.0142 | 0.0037 | -0.0137 | 0.0015 |
| $w_{M1} \cdot w_{OSE2}$ | -0.0063 | 0.0023 | -0.0062 | 0.0024 | -0.0063 | 0.0009 |
| $w_{M1} \cdot w_{M2}$ | -0.0043 | 0.0024 | -0.0044 | 0.0024 | -0.0044 | 0.0011 |
| $w_{E1} \cdot w_{C1}$ | -0.0018 | 0.0025 | -0.0018 | 0.0026 | 0.0007 | 0.0008 |
| $w_{E1} \cdot w_{L2}$ | 0.0040 | 0.0080 | 0.0040 | 0.0079 | -0.0117 | 0.0015 |
| $w_{E1} \cdot w_{OSE2}$ | -0.0117 | 0.0041 | -0.0119 | 0.0041 | 0.0004 | 0.0019 |
| $w_{E1} \cdot w_{M2}$ | -0.0028 | 0.0058 | -0.0026 | 0.0058 | -0.0118 | 0.0010 |
| $w_{C1} \cdot w_{L2}$ | -0.0073 | 0.0071 | -0.0074 | 0.0071 | -0.0118 | 0.0028 |
| $w_{C1} \cdot w_{OSE2}$ | -0.0058 | 0.0034 | -0.0058 | 0.0035 | -0.0054 | 0.0012 |
| $w_{C1} \cdot w_{M2}$ | -0.0141 | 0.0038 | -0.0139 | 0.0037 | -0.0061 | 0.0007 |
| $w_{L2} \cdot w_{OSE2}$ | -0.0432 | 0.0110 | -0.0434 | 0.0110 | -0.0467 | 0.0045 |
| $w_{L2} \cdot w_{M2}$ | -0.0271 | 0.0116 | -0.0268 | 0.0116 | -0.0404 | 0.0025 |
| $w_{OSE2} \cdot w_{M2}$ | -0.0278 | 0.0058 | -0.0273 | 0.0058 | -0.0227 | 0.0014 |
| $Y_2 \cdot w_{OSE1}$ | 0.0015 | 0.0049 | 0.0018 | 0.0049 | 0.0012 | 0.0033 |
| $Y_2 \cdot w_{M1}$ | 0.0092 | 0.0051 | 0.0092 | 0.0050 | 0.0070 | 0.0025 |
| $Y_2 \cdot w_{E1}$ | 0.0211 | 0.0112 | 0.0208 | 0.0112 | 0.0209 | 0.0048 |
| $Y_2 \cdot w_{C1}$ | -0.0015 | 0.0082 | -0.0007 | 0.0081 | 0.0041 | 0.0041 |
| $Y_2 \cdot w_{L2}$ | -0.0701 | 0.0201 | -0.0706 | 0.0201 | -0.0452 | 0.0142 |
| $Y_2 \cdot w_{OSE2}$ | 0.0300 | 0.0107 | 0.0308 | 0.0109 | 0.0236 | 0.0070 |
| $Y_2 \cdot w_{M2}$ | 0.0126 | 0.0072 | 0.0134 | 0.0072 | 0.0167 | 0.0038 |
| $Length$ | 0.1598 | 0.0875 | 0.1683 | 0.0878 | 0.0332 | 0.0512 |
| $CAP1_P$ | 0.0111 | 0.0286 | 0.0105 | 0.0287 | – | – |
| $CAP1_{WT}$ | 0.1880 | 0.1042 | 0.1697 | 0.1081 | – | – |
| $User$ | 0.0812 | 0.0605 | 0.0815 | 0.0602 | -0.0140 | 0.0262 |
| $Rt$ | -0.4096 | 0.0971 | -0.4105 | 0.0970 | -0.5289 | 0.0365 |
| $Mills$ | 0.0113 | 0.1644 | – | – | – | – |
| Adjusted $R^2$ | 0.9639 | | 0.9635 | | 0.8124 | |

Notes : N=171, T=4. The Heckit standard errors are unadjusted.

Table C.2: Cost function for NVI production utilities (Within-SURE)

| | SURE | | Iterated SURE | |
|---|---|---|---|---|
| Variable (in log) | Coef. | Std. Error | Coef. | Std. Error |
| $Y_1$ | 0.9700 | 0.0895 | 1.0127 | 0.0756 |
| $w_{L1}$ | -0.0375 | 0.0554 | -0.0213 | 0.0527 |
| $w_{OSE1}$ | 0.0525 | 0.0117 | 0.0512 | 0.0127 |
| $w_{M1}$ | 0.2605 | 0.0139 | 0.2629 | 0.0150 |
| $w_{E1}$ | 0.3817 | 0.0471 | 0.3426 | 0.0456 |
| $w_{C1}$ | 0.3428 | 0.0377 | 0.3646 | 0.0375 |
| $Y_1 \cdot Y_1$ | 0.2661 | 0.0670 | 0.2573 | 0.0578 |
| $w_{L1} \cdot w_{L1}$ | 0.0637 | 0.0206 | 0.0668 | 0.0205 |
| $w_{OSE1} \cdot w_{OSE1}$ | 0.0211 | 0.0031 | 0.0193 | 0.0030 |
| $w_{M1} \cdot w_{M1}$ | 0.1013 | 0.0060 | 0.1166 | 0.0051 |
| $w_{E1} \cdot w_{E1}$ | 0.0520 | 0.0143 | 0.0518 | 0.0136 |
| $w_{C1} \cdot w_{C1}$ | 0.0801 | 0.0133 | 0.0844 | 0.0121 |
| $Y_1 \cdot w_{L1}$ | -0.1074 | 0.0254 | -0.0776 | 0.0231 |
| $Y_1 \cdot w_{OSE1}$ | 0.0085 | 0.0091 | 0.0071 | 0.0081 |
| $Y_1 \cdot w_{M1}$ | 0.0141 | 0.0075 | 0.0278 | 0.0066 |
| $Y_1 \cdot w_{E1}$ | 0.0697 | 0.0193 | 0.0576 | 0.0172 |
| $Y_1 \cdot w_{C1}$ | 0.0150 | 0.0197 | -0.0146 | 0.0174 |
| $w_{L1} \cdot w_{OSE1}$ | 0.0026 | 0.0048 | 0.0055 | 0.0047 |
| $w_{L1} \cdot w_{M1}$ | -0.0216 | 0.0056 | -0.0306 | 0.0053 |
| $w_{L1} \cdot w_{E1}$ | 0.0164 | 0.0143 | 0.0155 | 0.0141 |
| $w_{L1} \cdot w_{C1}$ | -0.0610 | 0.0132 | -0.0571 | 0.0127 |
| $w_{OSE1} \cdot w_{M1}$ | -0.0006 | 0.0033 | -0.0011 | 0.0031 |
| $w_{OSE1} \cdot w_{E1}$ | -0.0232 | 0.0043 | -0.0204 | 0.0040 |
| $w_{OSE1} \cdot w_{C1}$ | -0.0011 | 0.0039 | -0.0033 | 0.0035 |
| $w_{M1} \cdot w_{E1}$ | -0.0538 | 0.0050 | -0.0539 | 0.0047 |
| $w_{M1} \cdot w_{C1}$ | -0.0265 | 0.0047 | -0.0309 | 0.0041 |
| $w_{E1} \cdot w_{C1}$ | 0.0086 | 0.0099 | 0.0070 | 0.0091 |
| $CAP1_P$ | – | – | – | – |
| $CAP1_{WT}$ | – | – | – | – |
| Adjusted $R^2$ | 0.6834 | | 0.5773 | |

Notes: N=17, T=4.

Table C.3: Cost function for NVI distribution utilities (Within-SURE)

| Variable (in log) | SURE Coef. | SURE Std. Error | Iterated SURE Coef. | Iterated SURE Std. Error |
|---|---|---|---|---|
| $Y_2$ | 1.0066 | 0.0878 | 1.0841 | 0.0466 |
| $w_{L2}$ | 0.0246 | 0.0617 | 0.0629 | 0.0644 |
| $w_{Y_1}$ | 0.7056 | 0.0599 | 0.7326 | 0.0595 |
| $w_{OSE2}$ | 0.1351 | 0.0162 | 0.1549 | 0.0170 |
| $w_{M2}$ | 0.1489 | 0.0151 | 0.1844 | 0.0153 |
| $Y_2 \cdot Y_2$ | 0.0278 | 0.1021 | 0.1200 | 0.0542 |
| $w_{L2} \cdot w_{L2}$ | -2.1222 | 0.5596 | -3.0379 | 0.2969 |
| $w_{Y_1} \cdot w_{Y_1}$ | 0.2857 | 0.1170 | 0.1488 | 0.1170 |
| $w_{OSE2} \cdot w_{OSE2}$ | 0.0270 | 0.0185 | 0.0513 | 0.0621 |
| $w_{M2} \cdot w_{M2}$ | 0.0659 | 0.0201 | 0.1081 | 0.0106 |
| $w_{L2} \cdot w_{Y_1}$ | 0.2952 | 0.0994 | 0.5102 | 0.0527 |
| $w_{L2} \cdot w_{OSE2}$ | -0.0078 | 0.0743 | -0.0894 | 0.0394 |
| $w_{L2} \cdot w_{M2}$ | 0.1018 | 0.0482 | 0.0023 | 0.0256 |
| $w_{Y_1} \cdot w_{OSE2}$ | -0.1479 | 0.0314 | -0.1000 | 0.0167 |
| $w_{Y_1} \cdot w_{M2}$ | -0.0403 | 0.0264 | -0.0403 | 0.0140 |
| $w_{OSE2} \cdot w_{M2}$ | -0.0136 | 0.0125 | -0.0897 | 0.0066 |
| $Length$ | 0.1366 | 0.1780 | -0.0058 | 0.0944 |
| $User$ | -0.2152 | 0.1529 | -0.2764 | 0.0811 |
| $Rt$ | -0.7484 | 0.0709 | -0.9141 | 0.0376 |
| Adjusted $R^2$ | 0.9196 | | 0.8332 | |

Notes: N=15, T=4.