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

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Abstract

This paper provides a new approach aiming at measuring the economies of vertical integration in a network industry. As other network industries, the water sector is characterized by different production stages which are often viewed as presenting economies of vertical integration. Some important coordination economies between successive stages and the fixed costs that would have to be duplicated in vertically disintegrated services may explain these economies. We propose in this paper to measure these economies by distinguishing between the technological economies of vertical integration and those resulting from market imperfections for the intermediate good. To illustrate our analyze, we use econometric methods consistent with panel data and we 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 economies of vertical integration are not significant in the water network industry.

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

JEL Codes: C33, L22, L95.

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Introduction

In most of network industries (electricity, gas, telecommunications, postal services, air, rail and urban transport) and in most countries, unprecedented transformations aiming at introducing more competition into what sectors which were considered as pure natural monopolies has been the main feature of the last decade. A key recommendation of policy-makers has been to broke up monopolies before introducing more competition.[1] Underlying 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 such a vertical disintegration of utilities can result in cost efficiency losses if production stages are characterized by strong economies of vertical integration. Sources of such economies of vertical integration are however often difficult to assess: A vertically integrated structure can be a cost effective system if there are substantial needs for coordination across stages, if markets for intermediary goods are not competitive enough or if there are high transaction costs associated with using these intermediary markets. 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.[2] However and to our knowledge, all the published empirical papers deal with the electric sector and none of them consider the market structure as a possible source of economies of vertical integration.[3] But as mentioned by Kaserman and Mayo (1991), the structure of utility costs is not independent of the market form. Economies of vertical integration may result from technological effects like a better coordination across stages or the non-duplication of fixed costs, but it can also be the consequence of market imperfections at upstream stages of the production process. If there

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[1] The question of liberalization of these industries, its economic implications and political issues are also in the heart of discussions on structural reforms in the EU since a few years, see European Commission (1999).

[2] Working on a sample of 74 US electric utilities observed in 1981, Kaserman and Mayo (1991) have shown that for a vertically integrated firm producing the sample mean generation and distribution levels, costs of vertically disintegrated production are 11.96 percent higher than for vertically integrated production. Also working on a sample of US electric utilities, Kwoka (2002) concludes that disintegration would result in substantial cost increase, 42 percent at the sample mean. Very recently, 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 going from 0.13 to 2.97 percent on average.

[3] Two approaches have been used for measuring economies of vertical integration. The first one is to test the separability among production stages as done by Lee (1995) or Hayashi et al. (1997) whereas the second introduced by Kaserman and Mayo (1991) is to rely on tests of subadditivity or economies of scope. None of these approaches explicitly consider that the cost function of a utility may differ according to the vertical organization of the sector.

are market imperfections, the allocation of inputs at the downstream stages will be distorted resulting in cost increase. A global measure of economies of vertical integration as proposed by Kaserman and Mayo (1991) or Kwoka (2002) does not allow to distinguish between the technological economies of vertical integration and the impact of market imperfection on the cost structure. Identifying the sources of economies of vertical integration is however crucial as disintegration may appear as a cost effective solution if upstream markets are competitive enough. The conclusion given by a global measure of vertical integration could be subject of controversy in such a case. By estimating separately the cost functions of vertically integrated and non-vertically integrated structures, we propose a procedure that explicitly makes the distinction between these two possible sources of economies of vertical integration. Moreover we take into account the fact that the technological characteristics of the water utilities may differ according to their vertical structure (vertically integrated versus not vertically integrated).

Within network industries, the water sector still seems to be a special case as direct competition and disintegration are not yet really oberved.[4] 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.[5] As in gas and electricity, the production stage of the industry seems potentially competitive. As in gas and electricity, the distribution stage presents some characteristics of a natural monopoly. The network of pipes is naturally monopolistic in the same sense as are the networks of pipes (in gas) and wires (in electricity). So there is no obvious reason in principle for limiting competition in the production, distribution, storage stages and any other part of the production process which does not appear to be a natural monopoly except if economies of vertical integration 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 economies of vertical integration in the water network industry.

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[4] England is a special case as 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 provider shares the use of another's assets is also authorized by OFWAT.

[5] There are also important differences between networks. For instance, electricity can be carried on long distances at a reasonable cost and without substantial losses whereas the supply of water is rather local. But these differences can not explain by themselves the absence of competition. For example, it is claimed that the absence of competition could be related to absence of long-distance grid in water. But absence of network interconnection can be a symptom of having been no competition in the past: if an industry is established as a group of regional monopolies, each of which has customers who are essentially captive, the incentives to connect to other monopolists' systems are minimal.

The paper is organized as follows. In the next section, we present the cost model and we briefly summarize the literature on vertical integration. Then in section 2, we present the empirical application. This application is based on a cost function estimate of the Wisconsin water utilities. We use a panel of 211 water utilities observed from 1998 to 2000. We first show that for a non-vertically integrated utility, there are no substantial economies of scale at the production and distribution stages whereas returns to scale are significantly increasing for the average vertically-integrated utility. Second, there are significant global economies of vertical integration only for large water utilities and in case of high intermediary water prices. Contrary to what has been found for other network industries (electricity and gas for instance), we show that the technological economies of vertical integration are not significant in the water network industry. We conclude this paper by drawing the main implications of these findings and by giving some directions for future researches.

1 Structure of production and vertical integration

Assessing the optimal vertical structure of a network industry requires to consider both the characteristics of the production technology (existence of technological economies of vertical integration) but also the nature of markets for intermediate goods (distortions due to market imperfection, existence of transaction costs). In previous studies, as in Kaserman and Mayo (1991) for example, the cost savings from the vertical integration of two successive stages of production are defined as the signed difference between the costs of connecting these stages across a market and the costs of connecting these stages through internal transfers. Such a measure of economies of vertical integration is a global measure that does not allow two distinguish between technological economies of vertical integration and effects of market imperfections. Another difficulty with the Kaserman and Mayo approach is that, in order to derive an index of economies of vertical integration, their model requires to nullify one output of the multiproduct cost function. As the cost function is usually approximated by a flexible form, it is likely that the point at which they evaluate economies of vertical integration is far away from the mean sample point. Hence, the precision of the cost approximation and the level of economies of vertical integration are questionable.

1.1 The nature of economies of vertical integration

There is an extensive literature on vertical integration. Grossman and Hart (1986), in their formal property rights theory, show how companies may reduce transaction costs by internalizing some activities. They also demonstrate how incomplete contracts may lead to greater vertical integration. Perry (1989), in a very interesting chapter on the determinants and effects of vertical integration, proposes the following definition for vertical integration: *"A firm is vertically integrated if it encompasses two single-output production processes in which either (1) the entire output of the upstream process is employed as part or all of the quantity of one intermediate input into the downstream process, or (2) the entire quantity of one intermediate input into the downstream process is obtained from part or all of the output of the upstream process".* If an industry is characterized by several successive production stages[6], a single firm may be able to produce the complementary products (or services) resulting from these different stages more profitably than a number of firms would do. Internalizing these vertically related activities is a more cost effective solution rather than purchasing them trough a market. Such industries are viewed as presenting at some stages economies of vertical integration, i.e. the total cost of producing is lower in a vertically integrated structure than in a disintegrated one.

The sources of economies of vertical integration although difficult to identify can be classified into three main categories: technological economies, transactional economies and 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. The economies of scope across stages can be related to the existence of important complementarities or coordination economies between two 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. It is for example the case for determining the optimal production or distribution capacity from a joint decision system concerning plant size and transmission system. Another source for economies of scope across stages is that some fixed costs can be shared or other inputs can be common.

Transactional economies may be another important determinant of vertical integration. The transaction costs associated to the use of a market for the intermediary product may be in some cases large. These transaction costs are associated to the design, the negotiation and the en-

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

forcement of contracts between buyers and sellers of the intermediate product. Also transactions involve costs in cases of asset specificity and incomplete contracts. The economies may come from a reduction in opportunistic behavior in the bilateral exchange, and a relative efficient conflict resolution machinery (Williamson (1985)).

Other drivers of vertical integration include market imperfections. If there are important scale economies at the production stage, the upstream firm may in such a case exercise monopoly power in pricing the intermediate product. This would result in inefficient combinations of inputs at the downstream stage. These inefficiencies come from problems of uncertainty on prices and also from the existence of private information concerning the costs of successive production process.

In assessing the optimal degree of vertical integration in a network industry, it is important to make the difference between the technological economies (better coordination, no duplication of fixed costs) that may favor a vertically integrated industry from the characteristics of markets for intermediate goods (existence of monopoly power and transaction costs) that 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, whereas integration with the intention of market foreclosure may, in some circumstances, reduce welfare.[7] Tirole (1988) summarizes the position as follows: *"These examples show that vertical integration or vertical restraints need not be detrimental to welfare, even when they are meant to increase monopoly profit. In such circumstances, the issue is the existence of monopoly power per se, not its by-products (vertical integration or vertical restraints). However vertical restraints may be privately desirable and at the same time socially undesirable. One should be cautious when assessing the effects of such restraints, but unqualified hostility toward vertical restraints is inappropriate".*

1.2 Vertical integration in network industries

1.2.1 Network industries

Network industries are often viewed as presenting important vertical economies of scale and scope in particular because of the existence of network spillover effects.

For instance in the electricity industry, vertically-integrated firm controls generation, trans-

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[7] We do not explicitly address in this paper the 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 on another. The interested readers may consult Hart, Tirole, Carlton, and Williamson (1990) or Rey and Tirole (2003) for recent surveys of this topic.

port and distribution to the final consumers. The main problem associated to this market organization is the lack of competitive incentive at the intermediary stages of the production process. However, it is well-known that electricity transmission requires a permanent control on the load moving through a transmission network grid because excessive flows of power may overload the grid leading to major shutdowns. In electricity transmission, expanded use of the grid tends to reduce the efficiency of transmission lines. While it may be technically feasible to internalize this effect within a single owner grid, the situation is made more complex if there are interconnecting grids. As electricity flows over the path of least resistance, it is impossible to force the electrons to stay on one grid if they prefer to reach their destination by another path. Increasing the load on the grid of an interconnected network may create externalities, either positive or negative. Therefore the need for coordination is obvious as the flow cannot be stored and moves at the speed of the light, and so rapidity and reliability are necessary qualities in the operation of networks.

In network industries the infrastructures of transport and distribution are essential inputs. The cost to construct another delivery system being prohibitive, the operator who controls the delivery system clearly controls the access of any upstream provider. And if the infrastructure owner is also an upstream provider, it is clear that the competition will be biased. This is a reason why the vertical integration may not result necessarily in efficiency gains.

1.2.2 Water network industry

The vertically-integrated water utility is still the norm in most of the countries. There are two main reasons justifying the persistence of such a market structure. First, a specific characteristic of the water supply services is that they are local services and that the production plant and the distribution networks are often very close (mainly because of network losses and alterations of the water quality during its transport). A long-distance transportation of water which requires high maintenance costs of infrastructures is often not a cost effective solution. Second, and as mentioned by Bisshop (2001), the water quality is essential and a number of issues arise from the possibility of competition between different producers (extracting and treating raw waters) in a same distribution network. These issues include the compatibility of water treatments done by the different producers, the origin of water in the network, or the responsability in case of sanitary problems. Hence, if the production and distribution stages are separately managed, the operator of the network has to check that the different supplyings are compatible.

Moreover, the coordination between the delivery service and producers is also important especially for the volume of water that must be injected into the network and the reserved water volumes. In particular, leakage is a problem: the producer and the water retailer should agree on how to recognize it in computing the quantity of water demanded by the users. The distribution stage may require from the production stage additional water input in order to compensate for a low rate of network return. Moreover, each stage of water supply (production and distribution) may resort to pressurization facilities. Once again, the coordination between the two stages is necessary for 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 while in the second case, the main system works thanks to gravity with the necessity of pressure reducers, the production stage must thus be located in upstream.

1.3 Measuring economies of vertical integration in a multi-stage industry

In this section, we propose a new approach to measure the impact of vertical integration in terms of economies of cost. Before us, several studies focusing on the electric sector have tried to assess the level of these economies of vertical integration. 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. Although interesting, this this indirect test does not allow to measure properly the economies of vertical integration.

More recently, Kaserman and Mayo (1991) have proposed to measure the economies of vertical integration by evaluating the economies of scope in a multiproduct cost framework. The idea is that a fully verticaly-integrated utility produces all stage outputs. By nullify one output, the production cost of this output can be assessed. In a two-stage production process, Kwoka (2002) has slightly 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 economies of vertical integration. First, 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. Second, this approach explicitly considers that the data generating process of the cost of a utility is the same whatever is the vertical organization of the sector. The cost model requires to examine a single cost function. The implicit assumption made by these authors is that 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. Last, the measure for economies of vertical integration proposed by Kaserman and Mayo (1991) and Kwoka (2002) is a global measure that does not allow to distinguish between technological determinants and market imperfections. As mentioned previously, such a distinction is crucial in term of policy implications.

For these reasons, we propose to estimate a different cost function for each type of utility. This requires to estimate a cost function for a vertically- integrated (VI) utility and cost functions for all type of non-vertically integrated (NVI) utility. From these cost function estimations, we can directly compare the cost structure of VI and NVI utilities in order to measure the global economies of vertical integration. In addition, we are able to identify the economies of costs related to technological effects by ruling out the problems of market imperfections (i.e. by fixing the price of intermediate good equal to its marginal cost).

1.3.1 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. The cost model can easily be extended to a higher number of successive stages.

Let us assume that the production process can be represented by two technological stages indexed by $s = 1, 2$, called respectively the production and the distribution stage. At the first stage, the utility uses k_1 inputs and k_2 at stage 2. We note Y_1 the intermediary output produced at the first stage and Y_2 the final output produced at the second stage. In a water network industry outputs Y_1 and Y_2 are respectively the water volume withdrawn and treated and the water volume sold to final users. In the same way, we denote Z_1 the capital and technical variables of the first stage and Z_2 the capital and technical variables of the second stage. The overall minimization program of the vertically-integrated utility writes:

$$\begin{aligned} \min_{X_1, X_2} \quad & \sum_{k1} w_{1k_1} \times X_{1k_1} + \sum_{k2} w_{2k_2} \times X_{2k_2} && (1) \\ s.t. \quad & Y_2 = \mathscr{g}^{vi}(X_1, X_2 | Z_1, Z_2), && (2) \end{aligned}$$

where w_1 and w_2 are respectively the factor prices of stages 1 and 2. Let us denote the optimal factor demands by $\widehat{X}_1^{vi}(Y_2, w_1, w_2 | Z_1, Z_2)$ and $\widehat{X}_2^{vi}(Y_2, w_1, w_2 | Z_1, Z_2)$. Then, we get the overall cost function of the vertically integrated utility:

$$C^{vi}(Y_2, w_1, w_2|Z_1, Z_2) = \sum_{k1} w_{1k_1} \times \widehat{X}^{vi}_{1k_1}(Y_2, w_1, w_2|Z_1, Z_2) + \sum_{k2} w_{2k_2} \times \widehat{X}^{vi}_{2k_2}(Y_2, w_1, w_2|Z_1, Z_2). \tag{3}$$

Notice that the first order conditions for the cost minimization require:

$$\frac{w_{1i}}{w_{1j}} = \frac{\frac{\partial g^{vi}(.)}{\partial X_{1i}}}{\frac{\partial g^{vi}(.)}{\partial X_{1j}}} \quad \forall i \in \{1, \ldots, k_1\}\ j \in \{1, \ldots, k_1\} \tag{4}$$

$$\frac{w_{2i}}{w_{2j}} = \frac{\frac{\partial g^{vi}(.)}{\partial X_{2i}}}{\frac{\partial g^{vi}(.)}{\partial X_{2j}}} \quad \forall i \in \{1, \ldots, k_2\}\ j \in \{1, \ldots, k_2\} \tag{5}$$

$$\frac{w_{1i}}{w_{2j}} = \frac{\frac{\partial g^{vi}(.)}{\partial X_{1i}}}{\frac{\partial g^{vi}(.)}{\partial X_{2j}}} \quad \forall i \in \{1, \ldots, k_1\}\ j \in \{1, \ldots, k_2\} \tag{6}$$

The cost minimization requires to equalize the relative marginal productivity of inputs at each stage, equations (4) and (5), but also between the two successive stages, equation (6). Notice that equalization of relative marginal productivity of inputs between stages is specific to a vertically integrated structure. This is an important explanation of the better coordination between stages induced in a vertically integrated structure.

1.3.2 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). Then Y_1 is sold to another separated utility (distribution utility) which uses it as an input of the distribution stage. We derive now the cost function associated to each utility.

The production stage, $s = 1$

Let's us consider first the production utility. We can derive the related variable cost functions:

$$\min_{X_1} \quad \sum_{k1} w_{1k_1} \times X_{1k_1} \tag{7}$$

$$s.t. \quad Y_1 = f_1^{nvi}(X_1|Z_1). \tag{8}$$

The production cost function is:

$$C_1^{nvi}(Y_1, w_1|Z_1) = \sum_{k1} w_{1k_1} \times \widehat{X}^{nvi}_{1k_1}(Y_1, w_1|Z_1), \tag{9}$$

where $\widehat{X}_1^{nvi}(Y_1, w_1|Z_1)$ gives the optimal demands of inputs. Notice that the first-order conditions for the cost minimization of a production utility are:

$$\frac{w_{1i}}{w_{1j}} = \frac{\frac{\partial f_1^{nvi}(.)}{\partial X_{1i}}}{\frac{\partial f_1^{nvi}(.)}{\partial X_{1j}}} \quad \forall i \in \{1, \dots, k_1\} \; j \in \{1, \dots, k_1\}. \tag{10}$$

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

The distribution stage, $s = 2$

Let us consider now 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:

$$\min_{Y_1, X_2} \quad w_{Y_1} Y_1 + \sum_{k2} w_{2k_2} \times X_{2k_2} \tag{11}$$

$$s.t. \quad Y_2 = f_2^{nvi}(Y_1, X_2|Z_2), \tag{12}$$

with w_{Y_1} the price of water input. The distribution cost function is the following:

$$C_2^{nvi}(Y_2, w_{Y_1}, w_2|Z_2) = w_{Y_1} \times \widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2) + \sum_{k2} w_{2k_2} \times \widehat{X}_{2k_2}^{nvi}(Y_2, w_{Y_1}, w_2|Z_2). \tag{13}$$

where $\widehat{X}_2^{nvi}(Y_2, w_{Y_1}, w_2|Z_2)$ gives the optimal demands of second stage inputs and $\widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2)$ the optimal derived demand in intermediate good. Notice that the first-order conditions for the cost minimization of a distribution utility in a non-vertically integrated structure are:

$$\frac{w_{2i}}{w_{2j}} = \frac{\frac{\partial f_2^{nvi}(.)}{\partial X_{2i}}}{\frac{\partial f_2^{nvi}(.)}{\partial X_{2j}}} \quad \forall i \in \{1, \dots, k_2\} \; j \in \{1, \dots, k_2\}, \tag{14}$$

$$\frac{w_{Y_1}}{w_{2j}} = \frac{\frac{\partial f_2^{nvi}(.)}{\partial Y_1}}{\frac{\partial f_2^{nvi}(.)}{\partial X_{2j}}} \quad \forall j \in \{1, \dots, k_2\}. \tag{15}$$

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. Notice that the two production structures, vertically-integrated *versus* disintegrated distribution, are equivalent if and only if the two following conditions are satisfied:

$$w_{Y_1} = \frac{\partial}{\partial Y_1} C_1^{nvi}(Y_1, w_1|Z_1) \tag{16}$$

$$\mathscr{G}^{vi}(X_1, X_2|Z_1, Z_2) = f_2^{nvi}(f_1^{nvi}(X_1|Z_1), X_2|Z_2) \tag{17}$$

that is if the intermediate good in a (non-vertically integrated) production utility is priced at its marginal production cost and if the technological process for a production utility is the same that for the production stage in a vertically-integrated utility.

Overall cost for a non-vertically integrated structure

The overall cost for a non-vertically integrated structure is equal to the variable cost of the production and the distribution stages minus the cost of water purchase for the distribution utility. This water purchase cost corresponds to a monetary transfer between the two services: it must be cleaned when considering the cost of the overall structure. Moreover, we consider that the produced volume Y_1 and supplied to the distribution utility corresponds to the optimal derived demand in intermediate good of the distribution utility $\widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2)$. Hence, the overall cost for a non-vertically integrated structure is:

$$\begin{aligned} C^{nvi}(Y_2, w_{Y_1}, w_1, w_2|Z_1, Z_2) =& C_1^{nvi}(\widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2), w_1|Z_1) + C_2^{nvi}(Y_2, w_{Y_1}, w_2|Z_2) \\ & - w_{Y_1} \times \widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2) \\ =& \sum_{k1} w_{1k_1} \times \widehat{X}_{1k_1}^{nvi}(\widehat{Y}_1^{nvi}(Y_2, w_{Y_1}, w_2|Z_2), w_{Y_1}, w_1, w_2|Z_1, Z_2) \\ & + \sum_{k2} w_{2k_2} \times \widehat{X}_{2k_2}^{nvi}(Y_2, w_{Y_1}, w_2|Z_2). \end{aligned} \tag{18}$$

1.3.3 Economies of vertical integration

Global economies of vertical integration

A direct comparison of C^{vi} and C^{nvi} allows to measure *the global economies of vertical integration*, that is the economies of integration resulting both from the technologies of production and from the possible market imperfection. Let us define GVI as a measure of such global economies of vertical integration in the following way:

$$GVI = \frac{C^{vi}(Y_2, w_1, w_2|Z_1, Z_2)}{C^{nvi}(Y_2, w_{Y_1}, w_1, w_2|Z_1, Z_2)} \tag{19}$$

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.

Technological economies of vertical integration

As mentioned previously, such a measure of economies of vertical integration, although interesting, may not be useful in practice as it mixes the technological effects (interdependance 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 non efficient allocation of inputs at the second stage). In order to distinguish between these market and technological effects, we propose the following approach. The idea is, first to compute the total cost of a non-vertically structure while imposing the intermediate good to be sold at its marginal production cost and, second to compare this cost to the one of a vertically integrated structure.

In order to implement this measure of technological economies of vertical integration, we proceed as follows. First, let us consider the non-vertically integrated producer. Following equation (9), the cost function writes:

$$C_1^{nvi}(Y_1, w_1|Z_1). \tag{20}$$

Let us assume that the market for the intermediary good Y_1 is perfectly competitive. In such a case we have:

$$w_{Y_1} = \frac{\partial}{\partial Y_1} C_1^{nvi}(Y_1, w_1|Z_1). \tag{21}$$

This condition defines the price of the intermediate good as a function of the first-stage output and first-stage input prices:

$$w_{Y_1} = w_{Y_1}(Y_1, w_1|Z_1). \tag{22}$$

Let us now consider the non-vertically integrated distribution utility. Its derived demand for Y_1 is $\widehat{Y}_1^{nvi}(Y_2, w_2, w_{Y_1}|Z_2)$, see equation (13). Imposing marginal cost pricing at the first stage we have:

$$\widetilde{Y}_1^{nvi}(Y_2, w_1, w_2|Z_1, Z_2) = \widehat{Y}_1^{nvi}(Y_2, w_2, w_{Y_1}(Y_1, w_1|Z_1)|Z_2). \tag{23}$$

The total cost of net of water purchases for a non-vertically integrated distribution utility with marginal cost pricing at the first stage writes:

$$\begin{aligned}\sum_{k2} w_{2k_2} \times \widehat{X}^{nvi}_{2k_2}(Y_2, w_2, w_{Y_1}|Z_2) =& \sum_{k2} w_{2k_2} \times \widehat{X}^{nvi}_{2k_2}(Y_2, w_2, w_{Y_1}(Y_1, w_1|Z_1)|Z_2)\\ =& \sum_{k2} w_{2k_2} \times \widehat{X}^{nvi}_{2k_2}(Y_1, Y_2, w_1, w_2|Z_1, Z_2)\\ =& \sum_{k2} w_{2k_2} \times \widehat{X}^{nvi}_{2k_2}(\widetilde{Y}^{nvi}_1(Y_2, w_1, w_2|Z_1, Z_2), Y_2, w_1, w_2|Z_1, Z_2)\\ =& \sum_{k2} w_{2k_2} \times \widetilde{X}^{nvi}_{2k_2}(Y_2, w_1, w_2|Z_1, Z_2)\\ =& \widetilde{C}^{nvi}_2(Y_2, w_1, w_2|Z_1, Z_2).\end{aligned} \tag{24}$$

Notice that using equations (20) and (23), we can write the cost function of the vertically non-integrated producer utility as a function of Y_2, w_1, w_2, Z_1 and Z_2:

$$\widetilde{C}^{nvi}_1(Y_2, w_1, w_2|Z_1, Z_2) = C^{nvi}_1(\widetilde{Y}^{nvi}_1(Y_2, w_1, w_2|Z_1, Z_2), w_1|Z_1). \tag{25}$$

It is possible to compute the overall cost of a non-vertically integrated structure by imposing condition (21) to hold. The resulting cost function is:

$$\widetilde{C}^{nvi}(Y_2, w_1, w_2|Z_1, Z_2) = \widetilde{C}^{nvi}_1(Y_2, w_1, w_2|Z_1, Z_2) + \widetilde{C}^{nvi}_2(Y_2, w_1, w_2|Z_1, Z_2). \tag{26}$$

Condition (21) makes the overall cost of a non-vertically integrated 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. Such *technological economies of vertical integration* are measured by the ratio:

$$TVI = \frac{C^{vi}(Y_2, w_1, w_2|Z_1, Z_2)}{\widetilde{C}^{nvi}(Y_2, w_1, w_2|Z_1, Z_2)} \tag{27}$$

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.

2 Vertical integration and costs for Wisconsin water utilities

The empirical part of the paper deals with the estimate of variable cost functions for Wisconsin water utilities. We first present briefly the data used for the econometric application.

2.1 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. This annual report provides financial information and water operation information including revenues and expenses, source of supply statistics, water equipment installed... One of the main interest of using that database is that the annual reports provides information of expenses by stage (source of supply, pumping, water treatment, transmission and distribution). However, one important limitation of this dataset is that we do not observe capital expenses by production stage. These informations allow to estimate a variable cost function associated to each stage.[8]

Production stages For simplicity reasons, we consider a two-stage production model: Production & Treatment (P&T) and Transmission & Distribution (T&D). These two stages are respectively indexed by $s = 1, 2$. The P&T stage corresponds to the resource extraction both from groundwater and surface water (source of supply expenses according to the PSC accounts), the transfer from the source of supply to the production facilities and the treatment of raw water (pumping expenses and water treatment expenses according the PSC accounts). The T&D stage corresponds to operations involved into the the transmission of water to final customers through distribution mains and customers services (transmission and distribution expenses according to the PSC accounts).

Utilities The PSC regulates three classes of water utilites (class AB, C and D) defined according to the number of final users. Due to data limitations, we were not able to keep in our sample the class D utilities (smallest utilities in term of the number of users). We have finally in our sample a panel of 204 services observed from 1997 to 2000. This sample is made of:

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

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[8] 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 this 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 economies of vertical integration.

- 17 *non-vertically integrated (NVI) production utilities.* A water utility belongs to this class if it operates as a water supplier for another service. The implicit assumption is that any positive water resale requires investments in network and transmission grid making the production function specific.

- 16 *non-vertically integrated (NVI) distribution utilities* for which more than half of the water sold to final users is bought from another utility. This 50% threshold has been chosen as it is high enough for making the production function specific.

Outputs As mentioned previously, we consider two production stages: Production & Treatment (P&T) and Transmission & Distribution (T&D) respectively indexed by $s = 1, 2$. 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.

Table 1: Use of inputs in the production process

Input	Production & Treatment	Transmission & Distribution
Labor (L)	×	×
Energy (E)	×	×
Water (Y_1)		×
Chemical (CH)	×	
Operation supplies and expenses (OSE)	×	×
Maintenance (M)	×	×

Inputs We consider 6 inputs that may enter the production process at the P&T stage and/or the T&D stage, see Table 1. The water utility variable cost is the sum of expenses for labor L, Energy E, Water purchased Y_1, Chemicals CH, Operation supplies and expenses OSE and Maintenance M. The labor input at stage s, L_s with $s = 1, 2$ is defined as the number of hours worked in the year. This input is obtained by dividing the labor expenses at stage s by the corresponding unit labor price w_{Ls}. See Appendix A for more details about the computation of w_{Ls}. The energy expenses and the quantity of energy used for water supply and pumping come from the annual report. The energy input E is measured in thousands of kilowatts per hour (MkWh). The unit energy price w_E is obtained by dividing the energy expenses by E. The water input Y_1 corresponds to the quantity of water purchased by a water utility to another in Mgal. The price is obtained by dividing the expenses for water purchase by Y_1. The Operation supplies and expenses OSE and Maintenance M inputs consists of various heterogeneous inputs. For example, expenses for M_2 corresponding to maintenance expenses for T&D include the following financial accounts: maintenance of distribution reservoirs and standpipes, maintenance of mains, maintenance of services, maintenance of meters, maintenance of hydrants and maintenance of other plant meter reading. It follows that it is quite difficult to express M and OSE as a physical quantity. Because of data limitations and this problem of heterogeneity, we use the following approach. We define the price indexes w_{OSEs} and w_{Ms} for $s = 1, 2$ by dividing the expenses by the output of the corresponding stage, Y_s. The 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 descriptives statistics may be found in Table 2.

Capital and technical variables The capital of the P&T stage 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 $Y_1 - Y_2$ corresponds mainly to the volume lost at the T&D stage but also to a few losses at the P&T stage and 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.

2.2 Vertical integration issues in the Wisconsin

Vertical integration and network efficiency One possible positive effect of vertical disintegration could be to induce more network efficiency at the downstream stage and so, more water savings. Due to market imperfection 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.

Table 2: Technological descriptive statistics

VI utilities: n=171

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	12.93	2.25	7.75	19.09
w_{OSE2}	US$/1,000 Mgals	66.08	73.74	0.10	435.61
w_{M2}	US$/1,000 Mgals	202.31	141.89	0.99	868.75
$Length$	Feet	252,186	275,575	17,435	1,731,558
$CAP1_P$	Gals/minute	4,175	5,760.64	0.00	33,200.00
$CAP1_{WT}$	Gals	1.40	2.11	0.00	20.07
$User$	-	3,137	3,775.86	57.00	22,919.00
Rt	%	0.83	0.09	0.48	1.00

NVI production utilities: n=17

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	109.05
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	269.34
$CAP1_P$	Gals/minute	79,029	204,338	650	876,000
$CAP1_{WT}$	Gals	10.79	18.86	0.30	79.00

NVI distribution utilities: n=16

Variable	Unit	Mean	Std. Dev.	Minimum	Maximum
Y_2	Mgals	717,247	626,336	131,223	2,377,548
w_{E2}	US$ / Mkwh	94.80	103.08	6.29	518.55
w_{Y_1}	US$/1,000 Mgals	0.97	0.35	0.47	1.79
w_{L2}	US$/Hour	13.93	2.11	10.90	19.07
w_{OS2}	US$/1,000 Mgals	56.97	39.95	3.24	150.78
w_{M2}	US$/1,000 Mgals	195.24	89.42	18.06	388.21
$Length$	Feet	395,508	307,998	87,677	1,098,054
$User$	-	5,526	5,104	1,174	19,569
Rt	%	0.91	0.07	0.75	1.00

Table 3: Network efficiency and vertical integration

		Network loss rate[(a)]				Network loss index[(b)]			
	Obs.	Mean	Min	Max	Stdev.	Mean	Min	Max	Stdev.
Distribution Utilities	64	0.094	0	0.252	0.065	0.193	0	0.632	0.140
Integrated Utilities	684	0.175	0	0.515	0.094	0.304	0	1.990	0.251
Total	748	0.169	0	0.515	0.095	0.295	0	1.990	0.246

[(a)]: 1–Volume sold / volume produced, in (%).

[(b)]: (Volume sold - volume produced) / network length, in (Mgal/Feet).

In Table 3, 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 (less than 10% on average versus more than 16% on average). This difference may be attributed to differences in term of network structure as it is clear that these two types of utilities have different networks. In order to take into account this possible effect, a network loss index has been computed. Results for this index are similar (and even stronger) to those obtained with the network loss rate. Distribution utilities tend to have less network losses than integrated services.

Vertical integration and water pricing Most of Wisconsin water utilities use block tariff with decreasing marginal prices. It is surprising to notice that marginal prices of water for integrated

Table 4: Water pricing and vertical integration

		Marginal Price, residential[(a)]				Fixed Charge, residential[(b)]			
	Obs.	Mean	Min	Max	Stdev.	Mean	Min	Max	Stdev.
Distribution Utilities	64	2.015	0.980	3.460	0.770	56.800	34.080	84.120	15.296
Integrated Utilities	684	2.024	0.813	4.587	0.760	60.110	18.000	136.080	21.048
Total	748	2.024	0.813	4.587	0.760	59.850	18.000	136.080	20.666
		Marginal Price, industrials[(c)]				Fixed Charge, industrials[(d)]			
	Obs.	Mean	Min	Max	Sdv.	Mean	Min	Max	Sdv.
Distribution Utilities	64	1.867	0.866	3.136	0.686	203.053	90.000	420.000	84.774
Integrated Utilities	684	1.793	0.703	4.080	0.685	183.760	59.280	564.600	72.457
Total	748	1.799	0.703	4.080	0.685	185.273	59.280	564.600	73.622

[(a)]: Marginal price for residential users (annual consumption of 60,000 gals).

[(b)]: Fixed charge in US$ per year for a 5/8 inches meter connection.

[(c)]: Marginal price for large commercial and industrial users (annual consumption of 300,000 gals).

[(d)]: Fixed charge in US$ per year for a 1 1/2 inches meter connection.

utilities and non integrated utilities are very similar. This is the case both for industrial and residential users. As there are some empirical evidences of monopoly power on the intermediate market for water, we were expected the marginal price to be higher for NVI than for VI firms. Finally, it is also surprising to notice that the fixed charges are similar. In the case of industrial users, the fixed charge of NVI utilities is even higher than the fixed charge of VI.

2.3 Cost model estimation

The well-known translog approximation (Christensen, Jorgenson, and Lau (1973)) is chosen to estimate cost functions as a convenient flexible functional form for computing substitution and network (density and scale) returns measures. It is as follows:

$$\begin{aligned}\ln(VC) &= \alpha_0 + \sum_i \alpha_i \ln w_i + \alpha_y \ln Y \\ &+ \frac{1}{2}\sum_i \sum_{i'} \alpha_{ii'} \ln w_i \ln w_{i'} + \frac{1}{2}\alpha_{yy}(\ln Y)^2 + \sum_i \alpha_{iy} \ln w_i \ln Y \\ &+ \sum_k \alpha_k \ln Z_k,\end{aligned} \tag{28}$$

where VC represents the variable cost, w the input prices, Y the output and Z the other variables (capital and technical variables). Parameters to estimate are : $(\alpha_0,\ \alpha_i,\ \alpha_y,\ \alpha_{ii'},\ \alpha_{yy},\ \alpha_{iy},\ \alpha_k)$. And we suppose that the cost function satisfies the following symmetric restrictions : $\alpha_{ii'} = \alpha_{i'i}$. To ensure homogeneity of degree one in input prices, we divide variable cost and input prices by the price of any input.[9] A system of input demand equations is derived according to Shephard's lemma as:

$$S_i = \alpha_i + \sum_{i'} \alpha_{ii'} \ln w_{i'} + \alpha_{iy} \ln Y, \tag{29}$$

where S_i is the cost share of factor i. The model of cost consisting of the cost function (28) and cost share equations (29) minus one[10] is the system to be estimated. The translog cost function is a second-order Taylor expansion that we estimate around the mean of observations (in logs). Hence, all right-hand side variables are normalized by their sample (geometric) means (namely a mean-scaling transformation). We add for each equation an error term independently and identically distributed. We rewrite the above system in a more compact way as follows:

$$Y = R\beta + \varepsilon, \tag{30}$$

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

[10] 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.

where Y is the $(MHT \times 1)$ vector of dependent variables, with M the number of equations in the cost system, H the number of utilities, T the number of period and K the number of parameters. R is the $MHT \times K$ matrix of regressors, β the parameter vector. As standard in panel data econometrics, the error term consists in an unobservable individual specific effect μ and a classical disturbance u. The term $\varepsilon = \mu + u$ is a $MHT \times 1$ vector.

Two different methods have been used to estimate the cost model. As discussed after, some variables in the left-hand side term of the system may be considered as endogenous. A way to treat this problem is to use instrumental variables (IV) estimators. We use the generalized method of moments (GMM, see Hansen, 1982) to estimate the parameter vector β. This method extends the IV method and has the advantage of not imposing distributional hypothesis on the error term. This method gives consistent estimator but it is well-known that it posseses good properties only for a large sample. As, we have only a limited number of observation for NVI production and distribution utilities, we prefer using a fixed-effects method on the seemingly unrelated regression (SUR, see Zellner, 1962) system. This method presents the advantage to avoid possible correlation between the regressors and the fixed term since this later vanishes after transformation of variables. However the major drawback is that it is not possible to identify the parameters of time-invariant regressors Moreover, the Within estimators are not efficient. These problems are partly solved. As the all regressors in our study varies with time, all associated parameters can be estimated. Then, use of an iterative procedure *à la Zellner* allows to increase the efficiency of the Within-SUR estimator.

Following Cornwell, Schmidt, and Wyhowski (1992), The GMM estimator with panel data is based on L orthogonality conditions: $E[A'(Y - R\beta)] = 0$, where A is a $MHT \times L$ matrix of valid instruments. For the equation m, we choose the instruments of Hausman and Taylor (1981)[11]: $A_m = [WX_m, X_{(1)m}, Z_{(1)m}]$, where $WX = \{X_{it} - \bar{X_i}\}$ for all i and t, and X the matrix of time-varying (exogenous and endogenous) variables, $X_{(1)}$ the matrix of time-varying exogenous variables and $Z_{(1)}$ the matrix of time-invariant exogenous regressors. Using these moment conditions approximated by their empirical counterpart leads to the GMM estimator of the system (30):

$$\hat{\beta}_{SGMM} = (R'A\hat{\Phi}^{-1}A'R)^{-1}R'A\hat{\Phi}^{-1}A'Y, \tag{31}$$

where $\widehat{\Phi} = \frac{1}{H}\sum_{h=1}^{H} A'_h \hat{\Sigma} A_h$, with $\hat{\Sigma} = \frac{1}{H}\sum_{h=1}^{H} \hat{\varepsilon}_{h,IV}\hat{\varepsilon}'_{h,IV}$ and $\hat{\varepsilon}_{h,IV}$ is the first-step Instrumental Variable residual.

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[11] There exist even more efficient Instrument-Variable procedures, see Amemiya and MaCurdy (1986), and Breusch, Mizon, and Schmidt (1989). However the number of overidentifying restrictions is already important: adding more instruments can lead to bias estimates.

The second method (Within-SUR) used to estimate the system of equations first consists in transforming using the Within operator (W) all the variables of the system. $\tilde{Y}$ and $\tilde{R}$ denote the variables transformed by W. In the trnsformed model, the individual fixed effets μ are ruled out, but they can be estimated *ex post.* Second, the equations of system are simultaneous estimated by the SUR method. This procedure consists in estimating the trnasformed model by OLS, equation by equation. Then, we the complete system is reestimated by a GLS method and using the Within residuals of the first stage. Last, the Within-SUR estimator of the system (30) writes:

$$\hat{\beta}_{WSUR} = [\tilde{R}'(\hat{\Sigma}_{\varepsilon}^{-1} \otimes I_{HT})\tilde{R}]^{-1}\tilde{R}'(\hat{\Sigma}_{\varepsilon}^{-1} \otimes I_{HT})\tilde{Y}, \tag{32}$$

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

2.4 Estimation results

2.4.1 Cost estimates

In order to use the GMM method presented in the previous paragraph, it is necessary to make some exogeneity assumptions for constructing the orthogonality conditions for the GMM criterion. There are several sources of potential endogeneity in our system of equations.

First, the assumption that WUies take output levels as given is quite doubtful in practice. In particular in our model, the water volumes produced are typically chosen by the services. When the water utility is vertically integrated, it has to choose the produced volume that depends on the demand of customers. Such a choice also affects the quality of network (network return). Indeed, there is an important relationship to take into account between the produced water volume, the final sold water volume and the water volume that is lost mainly because of leaks on the distribution network. And as showed by Garcia and Thomas (2001), there is a possible trade-off between production stage and distribution stage in order to satisfy the demand. Hence, the water utility could achieve an higher efficiency in water distribution, but is limited by the prohibitive costs of repairs, and could prefer to increase production and to keep the water network rate of return constant. Second, as some input unit prices are computed as a function of water output, they may be endogenous if the latter is. For these reasons, we assume that water volumes and the water network rate of return are endogenous in our model. Morever, we control the possibility of endogeneity of input prices by detecting departure from the null hypothesis using a Hansen test.

Vertically-integrated water utilities The 50 parameters of the variable cost function for VI utilities have been estimated by GMM, see Table C.1 in Appendix C. In fact and taking into account the cost share equations, the total number of parameters to be estimated is 113. However, since there are some cross-equation parameter restrictions, all structural parameters enter the cost equation. As said above, we have chosen the Hausman-Taylor's instruments, so that 183 instruments are used for our estimation. We have checked for the validity of moment conditions with the Hansen test statistic, which equals 60.25 with 70 degrees of freedom. The p-value of the test is 0.7906. Our model specification and the choice of instruments are not rejected at the 5 percent level. Table C.1 gives estimate of the variable cost functions for the VI utilities. Recall that in this case the cost related to each studied stage depends not only on its own variables (input prices as well as capital and technical variables) but also on the variables of the other stage.

Non-vertically integrated water utilities As the number of observations is limited to 68 for NVI production utilities and 64 for NVI distribution utilities, the cost function cannot be estimated using GMM. We use a Within-SUR model. Results of estimations is presented in Table C.2 and Table C.3.[12]

2.4.2 Results on cost elasticities

Marginal and average costs From the cost function estimates, we can compute the marginal costs for the VI service and for each technological stage for the NVI utilities, see Table 5. We report in the following table an estimate of the marginal and the average cost for the average utility. First, our estimates show quite low average and marginal costs. This is especially true for the NVI production utility. Second, these results give us a good idea of the cost differential between the two stages. In particular, for the average service the sum of marginal costs for each stage is greater than the overall marginal cost. The main explanation is that the NVI distribution utilities bear water purchased expenses whereas these expenses are not borne by the VI utilities. Third, when we compare MVC and AVC, the greater value of AVC for the average

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[12] 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 (648 observations). Then we have compared the estimated cost parameters with those obtained using the NVI production (68 observations) and distribution (64 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 mispecification of the econometric model.

Table 5: Estimates of marginal and average costs

		Average utility	Minimum	Maximum
NVI Production utility	MVC	0.2064 (0.0349)	0.0887	0.9924
	AVC	0.1959 (0.0250)	0.1111	1.3540
NVI Distribution utility	MVC	1.0248 (0.0394)	0.6862	2.4040
	AVC	1.1188 (0.0102)	0.7608	2.4358
VI utility	MVC	0.7589 (0.0594)	0.0317	2.4985
	AVC	1.2021 (0.0448)	0.0645	3.8196

Notes: MVC for marginal variable cost, AVC for average variable cost. For the average utilty, values in parentheses give standard errors computed using the *delta* method, see Kmenta (1986).

VI utility seems to indicate the existence of economies of scale. On the other hand, 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 sizes of the average VI and NVI utilities are significantly different. 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 significant smaller 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.

Cost elasticities We now consider the way the number of customers, the volume of production and the size of the network may affect the variable cost function. Considering both the number of customers and the length of network allows us to distinguish between returns to density (with respect to production and customers) and returns to scale in the water distribution process. The elasticity of production density EPD is computed as the inverse of elasticity of cost with respect to output ε_Y:

$$EPD = 1/\varepsilon_Y. \tag{33}$$

Returns to production density are increasing (economies of density), constant or decreasing when EPD is greater than 1, equal to 1 or less than 1, respectively. The returns to production density measure the cost savings that result from an increase of production holding the number of customers constant (i.e, the demand per user increases) as well as the size of network. It is important to point out that for NVI production utilities, returns to density and returns to scale can not be differentiated because there is no distribution network and the only customer is the distribution service that purchases drinking water for delivering to its users. The elasticity of customer density ECD is computed as the inverse of the sum of cost elasticities with respect to output ε_Y and with respect to the number of customers ε_{User}:

$$ECD = 1/(\varepsilon_Y + \varepsilon_{User}). \tag{34}$$

Returns to customer density are increasing, constant or decreasing when ECD is greater than 1, equal to 1 or less than 1, respectively. The returns to customer density measure the cost savings that result from an increase of production to satisfy the demand from new customers (here the demand per customer is constant) on a constant network. Elasticity of scale SCE is defined as the inverse of the sum of cost elasticities with respect to output and the number of users multiplied by 1 minus the sum of cost elasticities with respect to the capital variables K (among which network length):

$$SCE = (1 - \varepsilon_K)/(\varepsilon_Y + \varepsilon_{User}). \tag{35}$$

Returns to scale are increasing (economies of scale), constant or decreasing when SCE is greater than 1, equal to 1 or less than 1, respectively. Returns to scale measure the proportional increase of water volume and number of users made possible by a proportional increase of all inputs (including the capital variables). All scale measures are computed for the average utility (at the sample mean of the variables). Some interesting results can be highlighted from Table 6.

Table 6: Estimates of network returns for the average utility

		Average utility	Minimum	Maximum
NVI Production utility	EPD	–	–	–
	ECD	–	–	–
	SCE	1.4143 (0.3176)	0.7823	3.8924
NVI Distribution utility	EPD	1.0917 (0.0449)	0.9993	1.1952
	ECD	1.0049 (0.0618)	0.9261	1.0919
	SCE	1.0740 (0.0475)	0.9898	1.1671
VI utility	EPD	1.5839 (0.1155)	1.3937	2.1924
	ECD	1.4029 (0.1224)	1.2516	1.8601
	SCE	1.1668 (0.0879)	1.0409	1.5470

Notes: EPD for elasticity of production density, ECD for elasticity of customer density and SCE for scale elasticity. Recall that for the NVI production utility, the scale and the density elasticities can not be differenciated. For the average utility, values in parentheses give standard errors computed using the *delta* method, see Kmenta (1986).

On one hand, we find returns to production density significantly different from 1 at 5% level (both for the average VI utilities and NVI distribution utilities). Existence of such economies of density means that an increase of the demand per user will result in a decrease of its average cost. Moreover, these unexploited economies of density are greater when the water utility is vertically integrated. On the other hand, the returns to customers density are constant for the average NVI distribution utilities whereas they are strongly and significantly increasing (1.40, at 1% level) for the VI water utilities, at the sample mean. In the case of an integrated service, the network is not overloaded in terms of number of customers and so the network may accommodate more customers at a lower cost.

Concerning the NVI production utilities, the range for the scale elasticities is quite large indicating an important diversity in cost savings. However, for the average utility the returns to scale are not significantly different from 1 (constant returns). It is not surprising to find constant returns to scale for the average production utility since the production/generation stage in network utilities is often considered as potentially competitive. Nevertheless, the parameter related to the square of volume (in logarithm) is significantly positive, see Table C.2. This means that the returns to scale tend to increase with the water production. A possible interpretation of this result is that large production utilities benefit from high level of specialization and are able to exploit some scale economies. As a consequence, a merge of the smallest production services would allow to save on the production cost. At the sample mean, the returns to scale are significantly different from 1 at a 5% level for the average VI utility. Existence of economies of scale in this case means that an increase of the service (i.e. production, customers and network) would result in a decrease of the average cost. This result is not surprising as it is a common view to say that the provision of network facilities for drinking water supply exhibits scale economies of such significance that it can be regarded as a natural monopoly. Last, the returns to scale for the NVI distribution utilities are not significantly greater than 1. This means that on average the water utility has exploited the economies of scale: the size of the network is efficient. Besides the size of the network is larger on average for the NVI distribution services than for the VI water services.

2.4.3 Results on vertical integration

In this paragraph we give a measure of the level of economies of vertical integration. We will especially distinguish between the global economies of vertical integration (GVI) defined by (19) and the technological economies of vertical integration (TVI) defined by (27).

Overall economies of vertical integration In order to estimate the overall economies of vertical integration, we have simulated the cost for different levels of final output and different prices for the intermediate good, both for a vertically integrated utility and for a non-vertically integrated 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 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 total cost of production of the NVI structure, net of the 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 (19), for each $(Y_{2_k},w_{Y_{1l}}),\ldots,k=1,\ldots K$ and $l=1,\ldots L$.

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 to the different production level, the capital variable are adjusted according to the estimated statistical relationship. As the cost of a non-vertically integrated structure depends on the price for intermediary water, the overall economies of vertical are given for different level of the final output but also for different price of the intermediary good.

First, in the $(w_{Y_1}\times Y_2)$ space we both observe zones with global economies of vertical integration and with diseconomies. This means that there are both zones where a VI structure can produce water at a lower cost that a NVI structure and other where a NVI structure is more cost effective. We find 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. The cost structure is also characterized by economies of vertical integration when the intermediary price for water is high. This is quite intuitive as high intermediary prices for water correspond to high price caps and as a consequence create important distortions in term of input allocation.

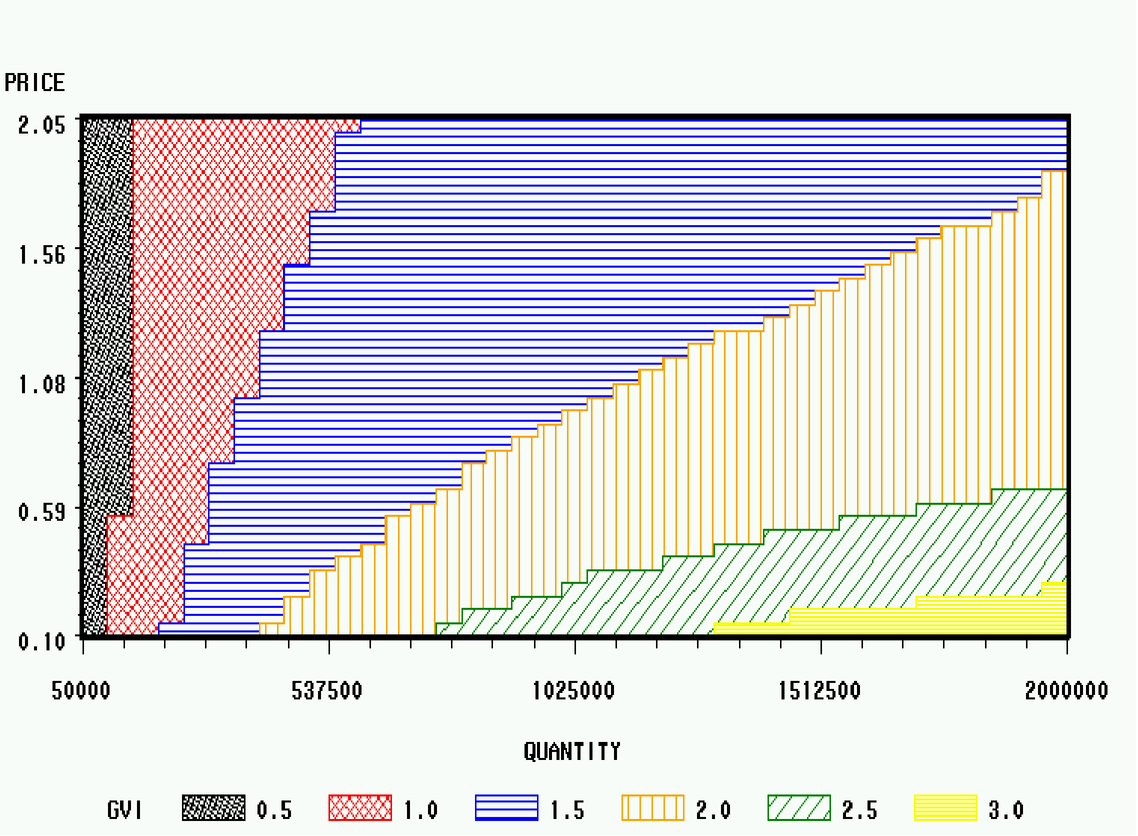

Figure 1: Global Economies of Vertical Integration

Second, the cost structure is characterized by global economies of vertical integration for low level of final output and high intermediary price for water. This result is directly related to previous comments. For those utilities integration involves significant technological and transactional economies, and suggests that undue fragmentation can lead to serious misallocation of resources. Fragmentation of responsibilities for planning, investment, operations, maintenance, and debt services may lead to lack of accountability and inefficiency because decision-makers do not have an appropriate level of control over decisions and actions that affect their efficiency. It is also likely that the market power on the intermediary good does not favor small utilities.

Third, for a given price of intermediary water the higher the final output is, the lower are global economies of vertical integration are important. This result reflects that global economies of vertical integration decrease with the final output. One explanation can be that for small water utilities the specialization of inputs across stages is quite limited because production processes are more simple. Hence, there are higher interdependences across stages for small utilities than for larger ones which means that a VI structure is more cost effective in that case (horizontal specialization).

Fourth, for a given level of final output the higher is the intermediary price, the higher are global economies of vertical integration. This is a very intuitive result. A high price of the intermediary water good means a high mark-up on the upstream market. This creates important distortions in inputs allocation at the downstream stage. In such a case being integrated would result in important cost savings.

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 levels for distribution and generation outputs, the efficiency gain from integration is 42 percent. We do also find global economies of vertical integration but only for small levels of final output. 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 electric flows across the network in accordance with the laws of physics, it can not be controlled through and command and control system. This may impose high externality costs in case of non integrated systems. The need for such a coordination between the different stages may be less stringent for a water network than for an electric system. But before deriving economic implications from this result, we still need to check that the presence of economies of vertical integration is not just the result of an imperfect upstream market.

Technological economies of vertical integration We now evaluate the level of technological economies of vertical integration. We proceed in the following way.

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

(2) Given that the volumes $\{Y_{1_1}, \ldots, Y_{1_K}\}$ are sold by the non-vertically integrated producer to the non-vertically integrated retailer utility at their marginal cost, we compute 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 the technological economies of vertical integration for $\{Y_{2_1}, \ldots, Y_{2_K}\}$ defined by equation (27).

Table 7: Technological Economies of Vertical Integration.

Y_2	MVC	TVI	Y_2	MVC	TVI
47694	4.878	0.272	856631	0.235	2.205
92882	2.003	0.523	897403	0.228	2.250
135553	1.247	0.724	938253	0.222	2.294
176885	0.915	0.889	979279	0.217	2.336
217437	0.730	1.031	1020320	0.212	2.377
257520	0.613	1.156	1061550	0.208	2.416
297312	0.533	1.267	1102753	0.203	2.454
336950	0.472	1.367	1144123	0.199	2.491
376515	0.430	1.459	1185600	0.196	2.526
416060	0.394	1.543	1227108	0.192	2.561
455630	0.367	1.622	1268655	0.189	2.594
495265	0.342	1.695	1310255	0.186	2.627
534970	0.323	1.764	1351920	0.183	2.658
574780	0.606	1.829	1393670	0.181	2.688
614670	0.292	1.891	1435380	0.178	2.718
654720	0.279	1.949	1477200	0.176	2.747
694845	0.268	2.005	1518850	0.174	2.775
735105	0.258	2.058	1560616	0.172	2.802
775515	0.250	2.109	1602365	0.170	2.828
815915	0.242	2.158	1644100	0.168	2.853

Table 7 gives the measure of the technological economies of vertical integration, as defined by equation (27). As mentioned previously, this measure is computed for different levels of final output. Remember that TVI ≤ 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 less than 200,000 Mgals). This means that if the upstream market is perfectly competitive, a vertically integrated structure is a cost effective solution only if the utilities are small enough. This result is difficult to compare with what has been found by Kwoka (2002) and Kaserman and Mayo (1991) working in the electric network industry because these papers do not distinguish between global and technological economies of vertical integration. However given the high level of global economies of vertical integration reported by these papers, it is likely that applying our framework to their data would result in finding technological economies of vertical integration for large electric utilities, an opposite conclusion to what has been found for water utilities. We believe that specialization of inputs by production stage (or asset specificity) is much more important than coordination across stages for large water utilities than for large electric utilities.[13] 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 presence of technological economies of vertical integration means that the efficient operation of the system as a whole will not be achieved without adequate mechanisms of central coordination. As mentioned previously, integration involves significant technological and transactional economies and suggests that undue fragmentation can lead to serious misallocation of resources. The 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 of production with a overall average cost closer to its minimum.

These results have some important policy implications in term of organization of the water industry. First, based on efficiency considerations there is no clear answer to the debate about separation of production & treatment and transportation & distribution stages. In case of a small water network, a vertically structure should be preferred. But separation of stages is a more cost effective solution in case of large water utilities if upstream market is competitive. In the case of separation of stages, one task of the water regulation authority will be to promote and ensure enough pricing efficiency on the upstream market. It is likely that given the limited number of production utilities such a market will suffer from a lack of competition.

Conclusion

As a matter of general principle, public policies should seek to isolate the natural monopoly elements in an industry and to prevent the firms entrusted with activities with natural monopoly characteristics from extending their monopoly power beyond the segment of the market where these characteristics exist. In network industries characterized by multi-stage production processes, achieving this objective requires to analyze the cost structure of vertically-integrated

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[13] 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 in to secure water sources. Technological economies of vertical integration from a better coordination of stages are likely small in the water industry.

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 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 some internalization of externalities. If these factors (in particular, economies of scope) are significant enough, 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 vertically integrated, vertical conduct regulation or measures of partial vertical separation will be needed to establish conditions for effective competition.

Identifying sources of economies of vertical integration is crucial in order to define the economic policy that must be implemented. Economies of vertical integration may result from technological effects as a better coordination across stages or the non-duplication of fixed costs, but it can also be the consequence of market imperfections at upstream stages of the production process. By estimating separately the cost functions of vertically integrated and non-vertically integrated structures, we have proposed a framework that allows to distinguish between the technological economies of vertical integration and the impact of market imperfection on cost structure.

These issues related to the vertical integration of water utilities have been investigated by estimating the production and distribution cost functions for some North American water utilities. More precisely, we have considered a sample of Wisconsin water utilities where the most common firm is an integrated utility responsible for all aspects of service provision in the area under its jurisdiction. The traditional view is that water utilities constitute as a whole a natural monopoly that must be regulated. However by considering separately the production and the distribution stages, we have shown that there are in fact some evidences that disintegration of these two stages may lead to cost savings (at the exception of the smallest services). Moreover, the returns to scale at the production and distribution stages are constant. Competition could have at each stage some welfare improving effects. However, introducing competition can raise serious difficulties, in particular for the network itself which can not be duplicated. At the production stage, common carriage between companies is possible but only on a limited scale: no such arrangements exist on a competitive basis and it occurs when for instance one company agrees to carry water for a neighboring company. Different possibilities are available for promoting competition at the distribution stage. These possibilities include among others the use of franchising, specifically service contracts or concessions, but also yardstick competition.

But focusing only on global economies of vertical integration to assess the optimal structure of an industry can be misleading as global economies of vertical integration may result from market imperfection or from technological effects. We have shown that there are no evidence for technological economies of vertical integration (at least for large utilities) between the production and distribution stages. This means that if the upstream market for the intermediary good is perfectly competitive, vertically disintegrated utilities should be promoted. This result for the water network industry appears to be different from what has been previously found by the applied literature 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 specificity) generates 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 technical diseconomies of vertical integration. Finally, it is interesting to notice that some countries are already engaged into a vertically disintegration process. This is for example the case in the Portugal where multi-municipal companies have been created in 1993 in order to provide the municipalities with treated bulk water and/or treatment of the collected wastewater.

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A Description of data sources

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 for defining OSE and M unit prices is that the 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 the corresponding 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 OES and M increases proportionally with the level of output. For the chemical input CH 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	310281	13552	3243731	381930
S_{L1}	0.15	0	0.52	0.11
S_{OSE1}	0.04	0	0.41	0.05
S_{M1}	0.08	0	0.62	0.08
S_{E1}	0.17	0	0.69	0.08
S_{C1}	0.07	0	0.28	0.06
S_{L2}	0.18	0	0.73	0.13
S_{OSE2}	0.08	0	0.49	0.08
S_{M2}	0.24	0	0.68	0.12

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

Variable	Mean	Min.	Max.	Stdev.
VC	1409974	27149	11985558	2683902
S_{L1}	0.320	0.110	0.578	0.139
S_{OSE1}	0.054	0.001	0.206	0.049
S_{M1}	0.171	0.003	0.468	0.091
S_{E1}	0.309	0.072	0.629	0.134
S_{C1}	0.146	0.000	0.395	0.108

Table B.3: Cost descriptive statistics for NVI distribution utilities, 64 observations

Variable	Mean	Min.	Max.	Stdev
VC	1010424	286355	3172686	791313
S_{L2}	0.05	0	0.17	0.04
S_{Y_1}	0.70	0.33	0.87	0.13
S_{OSE2}	0.19	0.05	0.38	0.08
S_{E2}	0.06	0	0.41	0.10

C Cost functions estimates

Table C.1: Cost function for VI utilities (GMM)

Variable (in log)	Est.	Stdev.	T-stat.	Parameter	Est.	Stdev.	T-stat.
Constant	9.721	0.370	26.07	$w_{M1} \cdot w_{M2}$	–0.004	0.002	–1.82
w_{OSE1}	0.025	0.003	7.79	$w_{E1} \cdot w_{C1}$	–0.002	0.003	–0.70
w_{M1}	0.060	0.004	16.17	$w_{E1} \cdot w_{L2}$	0.004	0.008	0.50
w_{E1}	0.063	0.017	3.83	$w_{E1} \cdot w_{OSE2}$	–0.012	0.004	–2.89
w_{C1}	0.071	0.015	4.68	$w_{E1} \cdot w_{M2}$	–0.003	0.006	–0.46
w_{L2}	0.312	0.013	24.60	$w_{C1} \cdot w_{L2}$	–0.007	0.007	–1.03
w_{OSE2}	0.179	0.007	25.10	$w_{C1} \cdot w_{OSE2}$	–0.006	0.004	–1.67
w_{M2}	0.168	0.005	32.28	$w_{C1} \cdot w_{M2}$	–0.014	0.004	–3.71
$w_{OSE1} \cdot w_{OSE1}$	0.015	0.002	8.68	$w_{L2} \cdot w_{OSE2}$	–0.043	0.011	–3.94
$w_{M1} \cdot w_{M1}$	0.036	0.003	14.33	$w_{L2} \cdot w_{M2}$	–0.027	0.012	–2.31
$w_{E1} \cdot w_{E1}$	0.026	0.004	6.83	$w_{OSE2} \cdot w_{M2}$	–0.027	0.006	–4.68
$w_{C1} \cdot w_{C1}$	0.030	0.003	8.98	Y_2	0.631	0.046	13.71
$w_{L2} \cdot w_{L2}$	0.066	0.033	1.97	$Y_2 \cdot Y_2$	0.015	0.048	0.30
$w_{OSE2} \cdot w_{OSE2}$	0.101	0.009	11.80	$Y_2 \cdot w_{OSE1}$	0.002	0.005	0.38
$w_{M2} \cdot w_{M2}$	0.090	0.005	16.78	$Y_2 \cdot w_{M1}$	0.009	0.005	1.82
$w_{OSE1} \cdot w_{M1}$	0.000	0.001	–0.02	$Y_2 \cdot w_{E1}$	0.021	0.011	1.86
$w_{OSE1} \cdot w_{E1}$	0.000	0.002	–0.12	$Y_2 \cdot w_{C1}$	–0.001	0.008	–0.08
$w_{OSE1} \cdot w_{C1}$	0.000	0.002	0.00	$Y_2 \cdot w_{L2}$	–0.071	0.020	–3.52
$w_{OSE1} \cdot w_{L2}$	–0.004	0.004	–0.97	$Y_2 \cdot w_{OSE2}$	0.031	0.011	2.82
$w_{OSE1} \cdot w_{OSE2}$	–0.005	0.003	–1.71	$Y_2 \cdot w_{M2}$	0.013	0.007	1.85
$w_{OSE1} \cdot w_{M2}$	–0.003	0.002	–1.24	$Length$	0.168	0.088	1.92
$w_{M1} \cdot w_{E1}$	–0.005	0.002	–2.79	$CAP1_P$	0.011	0.029	0.37
$w_{M1} \cdot w_{C1}$	–0.002	0.001	–1.35	$CAP1_{WT}$	0.170	0.108	1.57
$w_{M1} \cdot w_{L1}$	–0.014	0.004	–3.84	$User$	0.082	0.060	1.35
$w_{M1} \cdot w_{OSE2}$	–0.006	0.002	–2.58	Rt	–0.411	0.097	–4.23

Notes : N=171, T=4, $\bar{R}^2 = 0.96$.

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

Variable (in log)	Est.	Stdev.	T-stat.
Y_1	1.053	0.074	14.22
w_{L1}	0.001	0.052	0.02
w_{OSE1}	0.040	0.013	3.06
w_{M1}	0.255	0.014	17.62
w_{E1}	0.367	0.045	8.21
w_{C1}	0.337	0.036	9.40
$CAP1_P$	-0.664	0.285	-2.33
$CAP1_{WT}$	0.174	0.163	1.07
$Y_1 \cdot Y_1$	0.238	0.056	4.25
$w_{L1} \cdot w_{L1}$	0.073	0.021	3.51
$w_{OSE1} \cdot w_{OSE1}$	0.021	0.003	6.74
$w_{M1} \cdot w_{M1}$	0.117	0.005	23.16
$w_{E1} \cdot w_{E1}$	0.056	0.014	4.04
$w_{C1} \cdot w_{C1}$	0.084	0.012	6.92
$Y_1 \cdot w_{L1}$	-0.061	0.025	-2.44
$Y_1 \cdot w_{OSE1}$	0.009	0.008	1.08
$Y_1 \cdot w_{M1}$	0.024	0.007	3.47
$Y_1 \cdot w_{E1}$	0.042	0.023	1.85
$Y_1 \cdot w_{C1}$	-0.014	0.017	-0.83
$w_{L1} \cdot w_{OSE1}$	0.003	0.005	0.71
$w_{L1} \cdot w_{M1}$	-0.031	0.005	-5.85
$w_{L1} \cdot w_{E1}$	0.011	0.014	0.73
$w_{L1} \cdot w_{C1}$	-0.056	0.013	-4.38
$w_{OSE1} \cdot w_{M1}$	-0.001	0.003	-0.24
$w_{OSE1} \cdot w_{E1}$	-0.020	0.004	-4.86
$w_{OSE1} \cdot w_{C1}$	-0.004	0.004	-0.99
$w_{M1} \cdot w_{E1}$	-0.054	0.005	-11.23
$w_{M1} \cdot w_{C1}$	-0.031	0.004	-7.61
$w_{E1} \cdot w_{C1}$	0.007	0.009	0.75

Notes : N=17, T=4, $\bar{R}^2 = 0.769$

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

Variable (in log)	Est.	Stdev.	T-stat.
Y_2	0.916	0.038	24.31
w_{L2}	0.013	0.020	0.66
w_{Y_1}	0.795	0.022	36.58
w_{OSE2}	0.180	0.013	14.00
w_{M2}	0.012	0.012	1.01
$Length$	-0.069	0.085	-0.81
$User$	0.079	0.044	1.81
Rt	-0.963	0.031	-31.44
$Y_2 \cdot Y_2$	-0.044	0.034	-1.31
$w_{L2} \cdot w_{L2}$	0.012	0.008	1.51
$w_{Y_1} \cdot w_{Y_1}$	0.119	0.010	12.10
$w_{OSE2} \cdot w_{OSE2}$	0.094	0.007	14.27
$w_{M2} \cdot w_{M2}$	0.001	0.003	0.17
$Y_2 \cdot w_{L2}$	-0.018	0.010	-1.81
$Y_2 \cdot w_{Y_1}$	0.026	0.011	2.31
$Y_2 \cdot w_{OSE2}$	-0.014	0.007	-1.97
$Y_2 \cdot w_{M2}$	0.005	0.009	0.60
$w_L \cdot w_{Y_1}$	-0.012	0.007	-1.65
$w_{L2} \cdot w_{OSE2}$	-0.001	0.005	-0.25
$w_{L2} \cdot w_{M2}$	0.001	0.003	0.39
$w_{Y_1} \cdot w_{OSE2}$	-0.099	0.006	-17.03
$w_{Y_1} \cdot w_{M2}$	-0.008	0.004	-1.81
$w_{OSE2} \cdot w_{M2}$	0.006	0.004	1.62

Notes : N=16, T=4, $\bar{R}^2 = 0.932$.