WASTE WATER PURIFICATION IN ITALY:
COSTS AND STRUCTURE OF THE TECHNOLOGY

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Abstract

This work examines the purification processes of urban waste waters in Italy, with reference to costs and technology. The operating cost function of 103 plants shows that an increase in the sizes of the smaller ones generates strong economies of scale. A minimum efficient size at about 100,000 inhabitants, however, inhibits the creation of large monopolies at a local level and allows to maintain indirect competition. Among the explanatory variables of the costs, the pollution load of the waste water takes on a high statistical significance and suggests environmental prevention. The recent introduction of advanced treatments is expensive, but their costs are balanced by a notable improvement in the pureness of the effluent. As for general environmental policies, it is necessary to find good compromise between the need to improve the effectiveness of the existing plants and the investments in areas where the water purification service is still inexistent.

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1. Introduction

In the past decade Italy paid more attention to waste waters treatment. The change of public policy presents many evidences: the development of regional plans, the imposition of constraints aimed to increase the spatial scale of output and vertical integration, the definition of quality parameters for the return of waste waters to the environment and the support of the State by subsides and soft loans. The implementation through a new law (D. Lgs 152/99) of the EEC directives (91/271 and 91/676, regarding respectively waste waters and nitrate pollution), marks a further effort aimed at reducing the gap from the industrialized European countries (Drusiani, Romano, 1999).

In spite of the regulatory reorganization, the situation of the service still seems to be critical.

The percentage of inhabitants served is still low and the presence of a great number of small size plants bring up questions on efficiency. A large investment effort is necessary for the improvement of quality standards. We can find a lack of general infrastructure supporting the plants, such as reserve machinery, monitoring systems, remote control. More attention is necessary in the environmental allocation of the plants. The improvement of the output quality needs refinements in the treatment (advanced ones) and in the removal of suspended solids. The disposal of the sludge involves a greater attention as to the nature of the pollution load entering the plant, but also to the collection centers and to the thermal-recovery plants after the treatment.

"Quality" is important, but attention must also be dedicated to the "quantitative" aspects connected to water savings. This involves the possibility of re-using the treated waters for non potable civil uses (irrigation of green areas, auto-washes, city cleaning, parks and fountains) and for industrial ones.

From a different point of view, we need to direct the institutional transformation of the sector towards liberalization of the market and privatization. The reorganization of the entire water supply sector (Law no. 36/1994) is based on the creation of local firms, vertically integrated along the entire water supply cycle and regulated by concession regime through tender contracts. In this direction, the competitive context will be ensured by the presence of public and private firms and often with foreign partecipations.

The synthetic picture outlined above portrays a complex situation characterized by many questions regarding the priorities and the nature of the policies. No organic studies exist in Italy on the minimum efficient size and on the limits of the natural monopoly at a local level. In some areas of the country advanced treatment (tertiary) cycles and the reuse of the output water have been introduced, while in other areas waste water treatments are still completely absent. The rates and the budget of the operators are still defined through *cost plus* techniques. The Ministry's efficiency standards are being questioned by the companies and have not been concretely applied yet. Moreover, we don't know the exact relationship between the expenses sustained for the various treatment cycles and the effective contribution to the quality of the output and to environmental protection.

Our research has the objective of studying the operational characteristics and the costs of urban waste water purification in Italy. The analysis is based on economic and technological data, provided by a survey conducted by the association of public firms in the sector (Federgasacqua). In paragraphs 2 and 3 we examine, respectively, the various phases that characterize the process and the Italian situation. Paragraph 4 refers on the literature with particular attention to treatment costs, environmental constraints, explanatory variables of the costs and economies of scale. The description of the model follows in paragraph 5 and then we present the data base and the results (paragraph 6). We deep the relation between running costs and technology in the paragraph 7. Some considerations of policy conclude the work (paragraph 8).

2. Technological Aspects of the Purification Process

The activity of the sector is aimed at the reduction of polluting substances contained in the discharge water coming from habitations and firms. Through a network of sewage lines, waste waters are collected and conveyed to the purification plants where they are treated. The plants can have different characteristics depending on: the environmental context where they are located, the capability of purification, the operational structure, the design. Basically, two fundamental process lines are present and they work in parallel: the water line and the sludge one.

The water line is the principal activity of the cycle. It is made up of a series of treatments that depending on their sequence, properties and purposes can be classified as follows:

- *primary treatments:* they remove suspended and floating materials with physical and mechanical means such as grids, de-sanding, de-oiling and sedimentation;
- *secondary treatments:* these reduce the organic and pathogenic bacterial substances through biological (oxidation) and chemical (disinfecting) procedures;

- *advanced treatments:* they remove the “nutrients” (nitrogen, phosphorous) of the algal flora through biological (nitrification, de-nitrification) and chemical - physical (precipitation) processes.

Depending on the thoroughness and the operational structure of the cycle, the plant design could be very different. Particularly, the oxidation modes characterize the kind of plant (storage lakes, tricking filter, activated sludge, …). Often the advanced treatments are absent, also because of their expense. In all cases, the treatments produce two outputs: purified water, that is sent to receptor bodies (rivers, lakes, sea); residual sludge (composed for more than 30% by water), that requires further specific operations.

The sludge line has the aim to dispose the mud limiting environmental damage. It usually includes the following phases:

- *concentration* of the sludge mass: the volume is reduced by mechanical thickening;
- *biological stabilization*: the organic component is made inactive (i.e. not putrescible), through digestion by anaerobic or aerobic microorganisms;
- *dehydration:* the water component is reduced by mechanical (filtration, centrifuging, pressure) or thermic (drying) operations.

The production cycle can supply by-products with an economic value. Specifically, anaerobic sterilization of the sludge produces bio-gas that can generate electric energy. By “composting” the mud, it is possible to obtain manure useful for agricultural land. The not-exploited sludge is disposed by collection in controlled disposal facilities.

3. Structure of the Sector in Italy

According to recent assessments, waste water treatment in Italy satisfies 63% of the need[1]. An ISTAT survey of the sector situation in 1993[2] showed the presence of 8570 operating plants, corresponding to 58.3 million inhabitants equivalent served[3]. From the dimensional point of view, the average firm size is lower than 7,000 inhabitants. In fact[4], most of the plants (72%) are small, able to serve less that 2,000 inhabitants equivalent each; on the whole they serve only 4% of the total users. The large units,

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[1] PROACQUA (1996).

[2] ISTAT (1998)

[3] One “inhabitant equivalent” corresponds to an organic pollution load of 60 g. of BOD (Biochemical Oxygen Demand).

[4] The following information, unless otherwise specified, is taken from the ISTAT Report (1998).

with potential above 50,000 inhabitants equivalent, are just over 200 and altogether provide service to about 70% of the inhabitants.

As for the types of managing organizations, the primary role is played by public operators. 75% of the plants are run directly by municipalities, 13% by public organizations (municipalized companies, consortiums, agencies) while the remaining 12% offer space to private operators. In terms of the population served, the largest category is represented by strictly public bodies (46%), while municipal and private companies cover both a share of 27% of the users.

The existing facilities are run by about 2000 operators[5], each of which runs on average 4 or 5 plants. The fragmentation of the sector is particularly widespread in urban agglomerations. In this context, the City of Turin is an exception: it is served entirely, together with some suburban towns, by the large plant of the local consortium company, that is able to serve about two million equivalent inhabitants. A process of vertical integration is under way through a merger with the local water distribution operator[6].

As for the quality of the service supplied, 43% of the running plants perform exclusively primary level treatment, but the relating number of users is small (5% of the total). 51% of the structures carry out secondary level treatment, that covers the largest portion of the users (57%). The remaining share, equal to 3% of the total, provide advanced treatment cycles to 38% of the inhabitants.

A link emerges between the size of the plants and the degree of qualitative refinement of the service: the most advanced levels appear in the larger structures[7].

With reference to the final destination of treated waters, most of the plants (82%, corresponding to 76% of the inhabitants) discharge into a watercourse. Discharge into the sea accounts for most of the rest (2% of the plants, equal to 15% of the served inhabitants).

4. Some Proposals from Literature

In Italy there are few works about the relationship between the nature of the production process and the behavior of purification costs. Many researches, coming from engineering schools, study the different techniques and the ways they affect

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[5] Fondazione Rosselli (1995).

[6] This is the merger between the Consorzio Po Sangone and Azienda Acque Metropolitane S.p.A.

[7] Nevertheless Lucchetti e Rabotti (2000) maintain that ”even with the secondary and tertiary treatment, there can be difficulties in respecting the limits introduced by the European Community” regarding phosphorous and nitrogen.

environmental pollution, but often there is no connection to the economic aspects, especially concerning an empirical point of view.

The situation of the international literature is better. In the main industrialized countries, particularly the United States, researchers have dealt thoroughly with this problem. Applied research essentially follows two lines of study: the relationship between costs and the quality of the treatment, and costs and size of the plants (Table 1).

4.1. *Treatment Costs and Environmental Constraints*

The Holmes Analysis (1988) does not directly regard waste water but potabilization. The work however is useful for our field because it shows that the topic of water treatment cannot be separated from the wider context of prevention and environmental protection. Improvements in production achieved in agriculture often are more than compensated in negative by environmental costs deriving from fertilizers and pesticides found in the water.

The author’s objective is to provide indications on the economic effects coming from the reduction of agricultural pollution. Soil conservation policies are studied through the examination of the relations between the pollution level and the treatment expenses. Considering two cost functions models (engineering and hedonistic), he studies the impact of the degree of water pollution on the average cost.

A third function (in a log-linear form) is then tested on the relationship between the degree of pollution of the rivers of every region and some environmental variables of a topographical and geological nature (speed of the water flow, sediment transported, water collection basins).

Using the recursive relationship between the hedonistic cost function and the environmental aspects expressed by the third function, the author calculates the average cost of treatment per ton of polluting sediment discharged into the environment. The analysis shows that the reduction of agricultural pollution within a single region has modest effects on the purification costs of the waters of the same region. The benefits ”off-site” and “on site” do not coincide geographically. According to Holmes, environmental policies must be safeguarding all the territory. Moreover, the priority to the prevention push economic aspects into second place.

The works of Fraas and Munley (1984), McConnell and Schwarz (1992, 1993) regard the relationship between the investment costs and their effects in terms of the quality of the purified water returned to the territory.

Frass and Munley (1984) estimate two functions using a Cobb-Douglas form. The first concerns the expense of building 62 plants, reported in the documents of the tenders. The second involves the running costs of 178 operating plants. The analysis points out weak economies of scale for the capital costs and strong economies in the operating costs.

The most interesting aspect of the work regards the study of the relationship between the running costs and the amount of the pollution eliminated. The marginal cost curve shows a sharp rise above the “secondary treatment” levels. The authors invite local authorities to set particularly sophisticated purification standards only where environmental conditions effectively make them necessary.

McConnel and Schwarz (1992) deepen the topic examined above. They assess the choices of the local regulators in defining the level of reduction of pollution of the treated waste water. A useful model to define the optimal quality level of purification is tested. The estimate of a function relative to the running costs of 164 production units and to the building cost of 329 plants allowed them to point out the presence of economies of scale, but especially to test the relationship between costs and pollution level of waste water.

The results lead to a critical judgment of the investment choices made by local authorities. In most cases the treatment level is defined without any preventive analysis of the quality of the input waste and the desired output.

In a subsequent work (1993), the authors confirm the previous observations. They emphasize the difficulty in managing the pollution level without paying attention to the technological standards that characterize the available plants.

Oron (1996) studies the treatment of waste water and its re-use. The cost function is minimized subject to environmental, social and technological constraints.

The evaluation of the convenience to the re-utilization of treated water regards agricultural irrigation. With the support of linear programming, a connection is created between technological and economical components. The simulation, based on a plant in the Negev Desert (Israel), has provided an assessment of the impact of the different variables on the cost function.

4.2. Explanatory Variables of Costs and Economies of Scale

Balmer and Mattson (1994) estimate engineering cost functions on a sample of twenty purification plants, characterized by the same processing technology and with sizes ranging from 7,000 to 650,000 equivalents inhabitant. The original input prices are substituted by standardized prices.

The average total cost per inhabitant and the average cost referred to the principal inputs (man power, electricity, material), indicate the presence of consistent economies of scale.

Knapp (1978) studies the running costs of 172 purification and sewage transportation plants in the United Kingdom. He tests a function of average cost per gallon of waste daily treated and a total cost function. The cross-section analysis by OLS takes numerous explanatory variables into consideration: treated volumes, degree of pollution of the water, quantity of suspended solids input and output from the plant. Specifically, the behavior of costs is examined according to the nature of the treatment and the environmental situations where the activity is performed. The author considers the rainfall, the effect of the final residue compared to the input volumes, the flow per person, the age of the plants and 13 dummies individuating each phase of the process.

The most significant result of the study regards the estime of an L – shaped average cost curve, showing strong economies of scale up to a volume of 10 million gallons per day (16.6 Mmc, million cubic meters, per year). The different types of treatment turn out to be important for the smaller plants, while over 30 million gallons per day (50 Mmc per year) this factor loses statistic significance. The BOD lowering and the percentage of the solids suspended in the input water take on a strong explanatory value, while the quantity of suspended solids in the output is not statistically significant. Similarly the rainfall and the age of the plants appear to effect only marginally the costs.

Given these results, Knapp is favorable to territorial allocations where the plants are fed by several neighboring towns, in order to benefit from economies of scale. However he warns of the diseconomies due to small densities and to the distances between collection and treatment of the sewage.

Rossi, Young and Epp (1979) examine some rural areas and take up the topic of economies connected to the combined treatment of domestic and industrial waste waters, compared to specialized plants for the domestic ones. The study refers to small structures (below 20,000 inhabitants served).

The analysis presents the estimate of a traditional cost function: $C=b\,(Q_E, Q_I, F_, P)$, where Q_E is the vector of the output quality, Q_I is the vector of the quality characteristics of the input waste water, F is the quantity treated and P the input price vector. This function is tested using an engineering simulation model that gives information on the behavior of costs when quality and quantity of the waste are varying. The assessment is built up combining the domestic discharges with those connected to the chicken farm. The results confirm the possibility of achieving strong economies through the saturation of plants and their size increase. It also shows that the combined collection of civil and industrial wastes increase the quantity but worsens the output quality. In any case, as economies of scale are greater than diseconomies related to the increase of the pollution of the water, the advantages of diversification are evident.

5. Basic Cost Model

Considering the characteristics of the sector and economic literature on the subject, the study of the purification activity of urban waste waters in Italy suggests the following cost function:

C = f (V, **Q**, **P**),

where:

C = Operating costs,

V = Volumes treated,

Q = Vector of quality characteristics,

P = Vector of input prices.

The cost (C) includes the expenses for technical and administrative management of the plant and maintenance. Capital service costs (financing charges and depreciation) are excluded because of lack of data.

The volumes of waste water treated (V) identify the hydraulic load weighting on the plant and are measured in millions of cubic meters per year.

The quality[8] characteristics of the waste water (**Q**) are the concentration of polluting substances and the incidence of excess sludge. Concerning the first one, in order to express correctly the purification commitment, we consider the amount of pollution removed (RECOD), which is equal to the difference between the COD levels of influent and effluent water[9]. Relating to the excess sludge, its incidence is given by the ratio between the weight of its mass (not yet dried) and the volume of treated water. The resulting parameter (IES) is measured in grams per liter.

As for input prices (P), some proxy were used, representing their average unitary costs. So for labor, the total cost was divided by the average number of workers (PL), the costs of materials (energy, reagents, spares, various) were referred to the number of inhabitants served (PC), while for sludge the expenses per ton of mass disposed was considered (PS).

By a Cobb-Douglas functional form, we tested the following basic model:

$$\ln C = \alpha + \beta \ln V + \gamma_1 \ln RECOD + \gamma_2 \ln IES + \delta_1 \ln PL + \delta_2 \ln PC + \delta_3 \ln PS + \varepsilon \qquad [1]$$

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[8] In the water sector, as in many other utility, quality represents a fundamental element of the output. For the Italian water industry, the "hedonic" cost functions shows a greater explanatory capacity compared to the traditional ones, based only on output quantity (Fabbri and Fraquelli, 2000). Similarly, the analysis of gas distribution sector highlights the importance of quality aspects linked to territorial constraints (Fabbri, Fraquelli, Giandrone, 2000).

[9] The COD (Chemical Oxigen Demand) is a parameter indicating the quantity of oxigen necessary to oxidate the organic and inorganic substances polluting the liquid. The COD value is correlated with the BOD level.

where ε represents a normal error.

Linear homogeneity in input prices requires the restriction:

$\Sigma\delta_i = 1 \qquad \text{for } i = 1,2,3$

6. Data Base and General Results

6.1. Data Base

The data employed come from a survey edited in 1996 by Federgasacqua, and supported by main public companies of the sector. A questionnaire containing information of a technical, economic and organizational nature was submitted to managers of plants having a potential capacity above 40,000 equivalent inhabitants. 169 cross-section observations were collected in this way. As some of these were incomplete or requiring further checks, in the present research 103 observations were considered; they regard plants situated in 11 Italian regions, belonging prevalently to the center and the north of Italy.

The data set gives a good representation of the sector. It corresponds to 40% of the inhabitants served by the plants belonging to the classes indicated above (medium and large sizes).

The operational profile of the units included in the data base is provided by the values of Table 2.

6.2. Explanatory Variables of Costs

The estimate of the function (1) by ordinary least squares (OLS), led to the results reported in Table 3. The explanatory capacity of the model appears good, with an Adjusted -R^2 equal to 0.924.

The volumes of treated water result the most significant variable in explaining the amount of cost, confirming the primary role of the hydraulic load. The value of the estimated coefficient (0.838) confirms international evidences and suggests a deeper study on costs and size relationship.

Among the quality variables, the sludge level (IES) has a strong explanatory significance. As indicated in Table 1, this parameter shows great variability due to notable differences in the liquids treated by the analyzed plants. As expected, also the amount of pollution removed (RECOD) shows a positive and significant correlation with the costs.

All input prices show parameter with expected sign and significant value. The role of unitary cost of materials should be noted. The expenses for this input are equal to 50% of the running costs.

6.3. Economies of Scale

The analyses of the behavior of costs with changes in output level has to focus on the volumes treated yearly by each plant. This variable provide a good approximation of the size of production. The cost function reported in Table 3 shows a β coefficient of 0.828. As this coefficient measures costs elasticity with respect to the hydraulic output, we can deduce that an extension of the scale activity determines lower than proportional increases in the total costs. It must be noted that Cobb-Douglas gives coefficient expressing the elasticity respect to the average output of the firms included in the data base. Substantially, the estimates show a general tendency for a reduction of unit cost with the increase of the productive "scale", but they do not allow us to gather information on firms greater or smaller than the average output.

The average unit cost of the analyzed units, shown in Figure 1, is a first useful support to generate more insights. The scatter diagram confirms the inverse relationship between the average unit cost and the volumes of activity. The downwards tendency seems very strong for smaller plants and more light with the increase in size. To assess this phenomenon, we estimated the total cost function on different intervals in order to test the behavior of output coefficient (β).

The data base was gradually restricted eliminating the observations related to smaller plants. β coefficient took on values that were not significantly different from 1 with outputs greater than 15.5 million cubic meters per year (Table 4)[10]. As further restrictions to the sample do not generate significant changes in the beta coefficient, we can individuate around 15 million cubic meters per year (about 100,000 inhabitants), the minimum efficient plant size[11]. This is much larger than the present average size (about 7,000 inhabitants).

We must point out that any constraints due to the location of the users and the conformation of the territory are not considered. Then the collection of water coming from different areas, could preclude the possibility to benefit of scale economies.

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[10] The results do not change if we exclude the plant with larger dimensions, that appears in Figure 1 quite isolated on the right.

[11] These results are very close to those obtained by Knapp (1978) for U.K.

7. Further Investigations on Technological Choices

7.1. Extension of the Model

The function (1) is based on fundamental cost drivers of the sector, but the different ways to manage the activity suggest to deep the analysis taking into account technical phases and level of refinement of production process.

To this aim, we added in the function (1) the vector of technical dummy variables (T). Relating to the water line, the treatments of primary and secondary level (grids, de-sanding, de-oiling, sedimentation, oxidation) are present in almost all of the plants, while advanced tertiary treatments are present only in 53% of the cases. So we test their impact by (TER) variable.

The sludge line is more diversified. The stabilization of the mass with aerobic digestion (DGAER) is an alternative to the anaerobic one. In the dehydration phase, it is useful to isolate the effects of filter-pressing (DISFIL) and centrifuging (DISCEN)[12]. Relating to sludge disposal, it is possible to produce electric energy by incineration (COGEN) or to use the mud in agriculture (COMAGR).

In order to pay attention to scope economies, we add the (INT) variable to have insights on vertical integration (water distribution, sewage collection).

The extended model is therefore:

$$\ln C = \alpha + \beta \ln V + \gamma_1 \ln RECOD + \gamma_2 \ln IES + \delta_1 \ln PL + \delta_2 \ln PC + \delta_3 \ln PS + \tau_1 TER +$$

$$+ \tau_2 DGAER + \tau_3 DISFILT + \tau_4 DISCEN + \tau_5 COGEN + \tau_6 COMAGR + \tau_7 INT + \varepsilon \qquad [2]$$

7.2. The Results of the Extended Model

Table 5 shows the parameters estimated for function [2]. Compared to version [1], model [2] shows an improvement of explanatory efficacy and an enrichment of understanding on effects of technological choices.

The fundamental variables (quantity, quality, prices) confirm substantially the previous estimates. The dummy related to the advanced treatments (TER) indicates a low significant effect of this process on the expenses, equal to an increase of 8%. This aspect must be related to the benefits evaluation, reported in the next paragraph.

A relevant effect of opposite sign is generated by the combined management (INT) of other water services (sewage collection and/or drinking water distribution). Vertical integration seems to produce significant scope economies.

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[12] Belt-press treatment was not taken into consideration, because it is used as an alternative to centrifuging.

The analysis of the sludge lines offers further insights. No cost differences emerge between aerobic and anaerobic digestion (DGAER). Both dehydration treatments appear to increase the expenses: filter pressing (DISFILT) for an amount of 14%, centrifuging (DISCEN), for about 11%. The use of mud to produce energy (COGEN) or manure (COMAGR) don't seem to influence significantly the costs.

7.3. Benefits of Advanced Treatments

In order to assess the advantages of having refined processes, the units were grouped into two categories differentiated by the presence of the advanced cycle. For each group, the average quantities of "nutrients" (phosphorous and nitrogen) were determined with reference to the influent and the effluent flow.

Table 6 shows the results about phosphorous. Advanced cycles show a quantity of this element in the effluent slightly less than the other units (-0.2 mg/l, -9%), but we must take into account that they treat waste waters that are considerably more polluted. In fact, the total lowering, obtained by difference between the input and output concentration, appears greater for an amount of 32%.

Even more convincing differences come from the comparison of the nitrogen[13] incidence. The results are shown in Table 7. The greater purity of the waters released from advanced plants is given by the ammonia concentration of the effluent, lower for 44%, but is particularly highlighted by the gap in the lowering, which is greater for 50%. The performances are higher than the most restrictive standards prescribed in the most recent regulations[14].

8. Policy Implications and Conclusions

The research requires further investigations but it allows some evaluations on firms management and public policies. The model shows a good explanation of the costs. Managers can find average standards to evaluate their level of cost while policy makers and regulators can find useful support about tariffs, efficiency, incentive schemes and financial aids to the investments.

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[13] The analysis involved the quantities of the element present in the ammonia form (ion NH4+), as the data related to the nitrous and nitric components were incomplete.

[14] The D. Lgs 155/99 prescribes a nitrogen reduction of 80% for plants operating in sensitive areas while the Table 7 shows that the facilities equipped with tertiary cycles reach an average reduction of 86% of the influent concentration.

It is necessary to emphasize that the removed pollution load (RECOD) has a very important role in explaining the variability of the costs. Therefore we can not forget the prevention measures. It is a matter of evaluating the trade-off between the cost of environmental protection and the savings connected to the reduction of the pollution of the liquid to be processes.

The sludge level (IES) turns to be just as important. It must be remembered that often the weight of this variable is neglected. In the new price cap method, set by the Italian Government, this factor is absent. As for the advanced processes, the results suggest that the greater costs compared to secondary processes are repaid by the considerable reduction of phosphorous and nitrogen levels. However, it would be necessary to compare these expenses with the needs for investments in the areas where the service is absent or the plants do not work adequately.

As for the organization of the process, significant costs saving are connected to vertically integrated structures (water distribution, sewage collection) . On the contrary, greater expenses are incurred in sludge dehydration, by centrifuging and filter presses treatments.

The analysis of the economies of scale provides useful indications on the set-up of the sector. The strong economies connected to the increase of the smaller sizes suggest a further regulatory effort. In the collection it is necessary to incentive the concentration of waste waters towards a greater production capacity[15]. On the other hand, a minimum efficient size of about 100,000 inhabitants gives the possibility to avoid large monopolies at a local level. The presence of a few production units, characterized by an efficient size, allows yardstick competition and tender mechanisms.

It must be pointed out that our analysis is based exclusively on the operating costs of purification. It does not involve capital and financial expenses, that are more correctly evaluable at Company level. The cost of fund provision suggest a strong dimensional increase of the Italian firms. Competition, however, can works if a sufficient number of large national and international firms are tendering for the management of a single local plants.

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[15] It is clear that this action must find a correct balance between the "economies of scale" and the cost of the infrastructures necessary for the conveyance of the waste waters towards the treatment plants.

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Table 1 - Modelling Costs of Wastewater services

Authors	Year	Objective	Model	Economies of scale
Knapp	1978	Cost analysis devoted to examine the presence and extent of economies of scale	Econometric average cost-function in operation and maintenance activity for a Britain sample of 172 plants	Strong and pervasive economies of scale up to 10 million gallons daily (16,6 millions of cubic meters per year).
Rossi, Young, Epp	1979	Convenience about joint treatment of industrial and municipal wastes	Engineering simulation model of average costs	Strong economies of size for the smallest community size (population served: 3,000-5,000) Strong economies of scale from 3,000 to 10,000 inhabitants served The quantity effect is dominant against the concentration pollution increasing
Fraas, Munley	1984	Treatment cost and plant performance for conventional pollutants at municipal wastewater treatment plants	Cobb-Douglas estimates for capital cost of construction, operation and maintenance costs	Low economies of scale for capital cost of construction and strong economies of scale for operating costs. Costs rise sharply beyond secondary treatment
Holmes	1988	Soil conservation policy examined by the relationship between soil erosion and water treatment costs	Estime of the relation between quality and standard engineering costs by a cubic spline function. Hedonic cost function model by Cobb-Douglas. Log linear model of the linkage between the regional water quality and environmental variables	Good economies of size in the short run linked to the operation and maintenance costs
McConnell Schwarz	1992, 1993	Modelling how local regulators choose design levels of BOD pollution reduction	Two steps model for the determination of effluent quality. Cobb-Douglas functional form is used for the estime of the regulation utility function and log linear form for operating costs, capital costs and actual effluent constraint	BOD removal exhibits economies of scale with respect to plant size. High influent concentration implies higher marginal costs of reaching target effluent levels
Balmer, Mattsson	1994	Study of operating costs of different sizes with similar process and similar effluent quality requirements	Engineering average costs functions of manpower, electricity, total costs at a plant level	Strong economies for manpower and electricity. No trend of increasing efficiency for chemicals and polymers
Oron	1996	Management modelling for optimal wastewater treatment, disposal and reuse	Linear programming optimization of an objective function including treatment method, treatment costs and effluent quality, transportation and effluent storage costs, cost for environmental and health control operation and maintenance expenses. The constraints express reduction about waste water quality for reuse, environmental control and health risks.	

Table 2 – Descriptive statistics of Database

Variables	*Mean*	*Standard deviation*
Equivalent inhabitants served (thousands)	162	236
Volumes of waste water treated (millions m^3)	14.8	24.3
Volumes treated/ Equivalent inhabitants served (m^3 per unit)	90	44
Residual sludge (tons)	8098	14546
Residual sludge /Volumes of treated water (mg/liter)	726	602
Influent pollution load (ICOD, mg/liter)	433	194
Effluent pollution load (ECOD, mg/liter)	52	24
Removed pollution load (RECOD, mg/liter)	381	191
Running costs/Volumes treated (lira per m^3)	312	157
Labor cost/Running costs (%)	32.2	12.0
Costs of materials/Running costs (%)	50.4	13.7
Sludge disposal cost/Running costs (%)	17.4	9.6
Labor cost/Employees (million lira)	65.9	23.6
Costs of materials/Equivalent inhabitants served (thousands lira)	12.1	8
Sludge disposal cost/Quantity disposed (thousand lira per ton)	93.6	57.7

Table 3 - Cost function of waste water treatment

Variables	*Coefficients*	*Parameters estimates*	*t-Statistics*	*P-value*
V	β	0.828	30.779	0.000
RECOD	γ_1	0.263	4.791	0.000
IES	γ_2	0.245	5.908	0.000
PL	δ_1	0.349	8.131	0.000
PC	δ_2	0.484	11.219	0.000
PS	δ_3	0.167	5.364	0.000
Constant	α	-5.642	-9.672	0.000
Number of cases = 103				
AR^2=0.918 F=191.25				

Figure 1 – Average cost and plant size

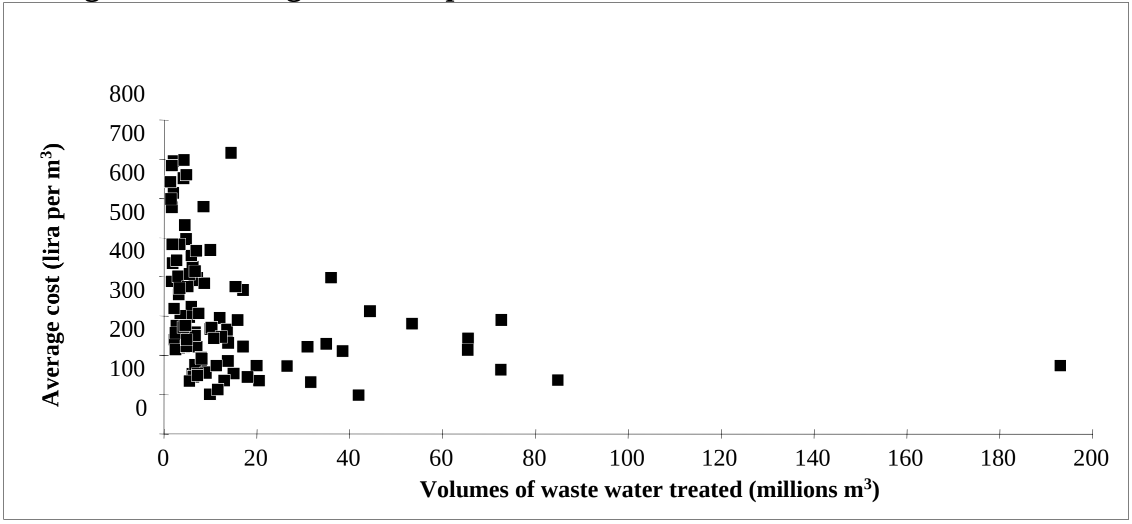

Table 4 – Plant size and economies of scale

	Yearly volumes treated	
Parameters	*< 15,5 mil. m^3*	*≥ 15,5 mil. m^3*
β	0.791	1.085
P – value	0.000	0.000
A-R^2	0.799	0.959
F	54.125	79.123
Number of cases	82	21

Table 5 – Extended cost function of waste water treatment

Variables	*Coefficients*	*Parameters estimates*	*t-Statistics*	*P-value*
V	β	0.813	26.472	0.000
RECOD	γ_1	0.254	4.585	0.000
IES	γ_2	0.203	4.202	0.000
PL	δ_1	0.368	8.500	0.000
PC	δ_2	0.477	11.162	0.000
PS	δ_3	0.154	4.900	0.000
TER	τ_1	0.081	1.492	0.139
DGAER	τ_2	-0.019	-0.243	0.809
DISFILT	τ_3	0.138	1.879	0.064
DISCEN	τ_4	0.111	1.714	0.090
COGEN	τ_5	-0.070	-1.158	0.250
COMAGR	τ_6	0.035	0.628	0.532
INT	τ_7	-0.145	-2.452	0.016
Constant	α	-5.495	-8.436	0.000
Number of cases = 103				
A-R^2=0.924 F=96.652				

Table 6 – Treatment and removal of phosphorous (mg/liter)

	Plants without advanced treatments (a)	*Plants with advanced treatments (b)*	*Difference (b)-(a)*	*Relative difference (b)/(a)-1*
Influent concentration	4.3	5.0	+0.7	+17%
Effluent concentration	1.6	1.4	-0.2	-9%
Lowering (absolute)	2.7	3.6	+0.9	+32%
Lowering (relative)	63%	72%	-	-

Table 7 – Treatment and removal of ammonia nitrogen (mg/liter of NH_4^+)

	Plants without advanced treatments (a)	*Plants with advanced treatments (b)*	*Difference (b)-(a)*	*Relative difference (b)/(a)-1*
Influent concentration	28.2	34.4	+6.2	+22%
Effluent concentration	8.7	4.9	-3.8	-44%
Lowering (absolute)	19.5	29.5	+10	+51%
Lowering (relative)	69%	86%	-	-

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