Alternative Concepts of Marginal Cost for Public Utility Pricing: Problems of Application in the Water Supply Sector

World Bank Staff Working Paper No. 259

May 1977

This paper is prepared for staff use. The views expressed are those of the author(s) and not necessarily those of the World Bank.

Prepared by: Robert J. Saunders
Jeremy J. Warford
Patrick C. Mann (Consultant)

Energy, Water and Telecommunications Department
Central Projects Staff

INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT

Staff Working Paper No. 259

May 1977

ALTERNATIVE CONCEPTS OF MARGINAL COST FOR PUBLIC UTILITY PRICING: PROBLEMS OF APPLICATION IN THE WATER SUPPLY SECTOR

In view of the difficulty of applying a standard benefit-cost approach to project evaluation in the water supply and sewerage field, the recommended solution - as in the case of other public utilities such as power and telecommunications - is to emphasize marginal cost pricing as a means of either signalling the justification for system expansion or of establishing a benchmark by which other social or economic objectives may be evaluated.

This paper discusses the rationale and problems of implementing marginal cost pricing for water supply and sewerage facilities. Many of the issues are now fairly well known, as the frequent references to their treatment in Bank operations make clear. However, there remains one critical area in which ambiguity remains. This stems largely from the different ways in which economists have tried to handle the problem of capital indivisibility, for which, by definition, marginal analysis is not well equipped.

The paper examines several frequently used definitions of marginal cost. Using a number of assumptions about long-term trends in costs, output and capital indivisibility, it evaluates each approach according to its implications for year-to-year price fluctuations, economic efficiency and revenue generation. As a result of these performance tests, the judgement is made that, largely due to the pervasive problem of capital indivisibility, it is not possible to establish a set of precise marginal cost estimation rules which can be followed mechanically in all circumstances. In practice, compromises are required, and the types of compromise that are suitable depend upon the degree of capital indivisibility, the stage of the project and program cycle at which the pricing decision is being made, the relevant elasticities of demand, and, not least, the prices which currently prevail.

Prepared by: Robert J. Saunders
Jeremy J. Warford
Patrick C. Mann (Consultant)

Energy, Water and Telecommunications Department
Central Projects Staff

ALTERNATIVE CONCEPTS OF MARGINAL COST FOR PUBLIC UTILITY PRICING: PROBLEMS OF APPLICATION IN THE WATER SUPPLY SECTOR

Table of Contents

Preface

In view of the difficulty of applying a standard benefit-cost approach to project evaluation in the water supply and sewerage field, the recommended solution - as in the case of other public utilities such as power and telecommunications - to emphasize marginal cost pricing as a means of either signalling the justification for system expansion or of establishing a benchmark by which other social or economic objectives may be evaluated.

The rationale for marginal cost pricing in public utilities is well known, and the principle has frequently been employed in World Bank operational work. There are however a number of complications involved in its practical application, many of which loom particularly large in a developing country context. A general problem is of course to reconcile the achievement of efficiency in resource allocation with a number of other criteria by which pricing policy may be judged. These include the extent to which the poor are able to obtain basic service; ease of administration; and impact on the financial viability of the water and sewerage authority concerned.

The efficiency objective itself is of course difficult to achieve even in the absence of such competing objectives, for it involves not only difficult political decisions (general increases in rates and costs reflecting variations in charges are always difficult to bring about), but also considerable measurement problems (particularly with regard to externalities and other manifestations of market failure). However, the most critical problem is that of determining exactly what is meant by marginal cost, the ambiguity in its definition stemming largely from the different ways in which economists have tried to handle the problem of capital indivisibility, for which, by definition, marginal analysis is not too well equipped. The primary objective of this paper is to help clear up this ambiguity.

After a brief discussion of the general problems of applying marginal cost pricing - which attempts to place the problem of capital indivisibility in a proper context - the main focus of the paper consists of an examination of several frequently proposed definitions of marginal cost. Using a number of assumptions about long-term trends in costs, output and capital indivisibility, each approach is evaluated according to its implications for year-to-year price fluctuations, economic efficiency and revenue generation. As a result of these performance tests, the judgement is made that, largely due to the pervasive problem of capital indivisibility, it is not possible to establish a set of precise marginal cost estimation rules which can be followed mechanically in all circumstances. In practice, compromises are required, and the types of compromise that are suitable depend upon the degree of capital indivisibility, the stage of the project and program cycle at which the pricing decision is being made, the relevant elasticities of demand, and, not least, the prices which currently prevail.

This paper owes much to the continued efforts of World Bank economists working in the energy, water supply, and telecommunications sectors to apply marginal cost pricing in a wide variety of difficult circumstances. The authors are grateful for helpful comments on the paper itself to Yves Rovani, Herman van der Tak, Anandarup Ray, Dennis Anderson, Gerald Alter, Charles Morse, Johannes Linn, Mohan Munasinghe, Yuji Kubo, DeAnne Julius, Jorge Culagovski, Ed Mishan, and Ralph Turvey.

Prepared by: Robert J. Saunders
Jeremy J. Warford
Patrick C. Mann

Energy, Water and Telecommunications Department

I. Pricing in Theory and Practice

1. Introduction

It is well known that demonstration of the economic justification of water supply and sewerage projects is frequently frustrated by difficulties of benefit measurement. Attempts that have been made in the course of World Bank operations to quantify the benefits of investments in the sector include:

- measurement of the impact on property values (water, sewerage and drainage),
- estimation of consumer's surplus on the basis of expenditures that would otherwise be incurred on private means of waste disposal (septic tanks, etc.),
- quantification of costs of walking to existing water sources,
- quantification of health benefits (water and sewerage),
- estimation of consumer's surplus from evidence of payments to water vendors, or planned investments in private sources of supply,
- quantification of irrigation benefits (sewerage),
- savings in costs of night soil collection (sewerage),
- estimation of consumer's surplus from historic evidence of willingness to pay in real terms,
- estimation of benefits for tourism and fishing (water and sewerage),
- estimation of flood control benefits (sewerage).

A number of these efforts were somewhat successful, but only because of exceptional circumstances that surrounded the projects in question. In general, the conclusion that stems from this experience is that conventional benefit-cost analysis (which seeks to evaluate water and sewerage investments by prediction of how such services are used, with imputed money values being placed on those uses by the analyst concerned) is rarely a tool that can be applied in practice in the water supply and sewerage sector.[1/] The private cost savings or consumer's surplus methods fail in many cases because the quality and quantity of the publicly provided service (the project) invariably is so different from that already obtained from private sources that existing consumer behavior furnishes little reliable evidence as to the magnitude of possible benefits. Where additional consumption, or the provision of a new or higher quality service is concerned, it is also usually impossible to satisfactorily disentangle the physical and other effects of the project from other influences on health, productivity, land values and so on. Consequently, unless there are exceptional circumstances in which the necessary evidence is clearly available, the quantitative results of standard benefit-cost analysis are too arbitrary to be useful in the water supply and sanitation sector. Instead, project analysis emphasizes the use of water and sewerage pricing policy as a means of demonstrating project justification.

1/ For further discussion of the kind of problems that are encountered in attempting to measure the benefits of investments in the water supply and sewerage sector, see Robert J. Saunders and Jeremy J. Warford Village Water Supply: Economics and Policy in the Developing World, Baltimore, The Johns Hopkins University Press, 1976; Roy Bahl, Stephen Coelen and Jeremy J. Warford Estimation of the Economic Benefits of Water Supply and Sewerage Projects, Syracuse University Research Corporation and IBRD, 1973; Economic Evaluation of Public Utility Projects (GAS 10) Public Utilities Department, IBRD, 1974; Jeremy J. Warford and DeAnne Julius, Economic Evaluation and Financing of Sewerage Projects, Energy, Water and Telecommunications Department, P.U. Report No. GAS 13, IBRD, February 18, 1977.

This has led of course to marginal cost pricing, which is the means by which consumers are given the opportunity to indicate whether or not the value to them of incremental output (the project) exceeds its cost. In effect, therefore, responsibility for the benefit-cost calculation is shifted from the project analyst to the beneficiaries themselves.

The rationale for marginal cost pricing in public utilities such as water supply is well known in institutions such as the World Bank,1/ and the principle has been employed in operational work many times. There are, however, a number of complications involved in its practical application, the most important being the definition of marginal cost itself.2/ Ambiguity in the definition of marginal cost stems largely from the different ways in which economists have tried to handle the problem of capital indivisibility, for which, by definition, marginal analysis is not too well equipped. The main objective of this paper is to help clear up this ambiguity. After a brief discussion of the general problems of applying marginal cost pricing-which attempts to place the problem of capital indivisibility in a proper context - the main focus of the paper consists of an examination of several

---

1/ The relevant principles are outlined in Ralph Turvey and Jeremy J. Warford Urban Water Supply and Sewerage Pricing (PUN 11), Public Utilities Department, IBRD, 1974.

2/ This general observation has been made many times. See for example: Alfred E. Kahn, The Economics of Regulation: Principles and Institutions, New York: John Wiley & Sons, Vol.1, 1970 , and Ralph Turvey "Practical Problems of Marginal Cost Pricing in Public Enterprises," Prices: Issues in Theory, Practice and Public Policy (Almarin Phillips and Oliver Williamson, Editors), Philadelphia: University of Pennsylvania Press, 1967, pp.124-134. However a rigorous attempt to reconcile the various definitions of marginal cost is lacking in the literature. See "Marginal Costs in Electric Rate Structures," Public Utilities Fortnightly, Vol. 98, No. 10 (November 4, 1976), p.53.

definitions of marginal cost that have been used, and evaluates them according to their implications for: price and revenue stability; economic efficiency and revenue generation.

2. Problems of Application

(a) Incorporation of Waste Disposal Costs in Water Pricing 1/

As applied to water supply, marginal cost pricing is a viable means of achieving efficient resource allocation, in the sense of ensuring that the benefits of expenditures in the sector exceed the costs. If price is set equal to marginal cost, and consumers demonstrate their willingness to pay such a price, it means that they place a value on the marginal unit consumed at least as great as the cost to the rest of society of producing that unit; output and consumption should therefore be expanded when system capacity is reached. If, on the other hand, the market clearing price is less than marginal cost, it can be assumed that there is oversupply: the cost of additional output exceeds the benefits.

While these principles can easily be applied to water supply, evaluation of sewerage projects via the pricing route presents a number of serious difficulties. It is obvious that when - as is common - sewage collection and disposal is financed from general revenues in such a way that there is no relationship between payment and benefits, the source of finance cannot be used to impute willingness to pay. Moreover, if sewage collection and disposal are charged for - as is normal 2/ - on the basis of metered water consumption, a revealed willingness to pay a given price

---

1/ For an extended discussion of this issue see Jeremy J. Warford and DeAnne Julius Economic Evaluation and Financing of Sewerage Projects, op.cit.

2/ A recent survey of World Bank projects shows that of 17 recent borrowers which have metered water supplies, 15 charge for sewerage on the basis of recorded water consumption.

simply indicates a value placed upon incremental water consumption plus its disposal. It is not possible to determine the extent to which willingness to pay refers to water supply alone or to water supply plus its sanitary disposal. Neither the allocation of costs or revenues between water and sewerage provides much guidance: consequently, to place normative significance on willingness to pay for water supply plus sewerage implies the judgement that sewage collection and disposal facilities are a necessary accompaniment of investments in water supply. While a popular notion, this is usually based upon intuitive judgement, and avoids the fundamental question of how to justify the sewerage component alone.

The advantage of placing a surcharge on water which reflects the incremental costs of the sewage disposal facilities required is that, given the objectives of disposing of waste water by means of sewage collection and disposal facilities, the incremental social cost of supplying water and disposing of waste will be minimized. While this does not justify the quality of the waste disposal method selected, it does ensure that given that quality, the water consumer is provided with an incentive to use the water supply and waste disposal facilities up to the point that the marginal benefit to him from so doing equals the marginal cost of expansion of the facilities. In this limited sense, optimality is achieved, and is a sufficient argument in favor of charging for sewage disposal - at least in part - on the basis of metered water use.[1/]

The discussion thus far is applicable only to those water users who are already connected to a sewer. The difficulty of determining willingness to pay for connection to any system by advance testing of the market is well known - sewerage being similar to water supply, electricity, and so on in this regard. Analysis of

---

1/ Such a policy tends to encourage optimal(i.e.,least social cost) reactions to pollution abatement measures. The rationale for this is described in J.Warford, T. Pellegrini, A. Kneese, and K. Maler, Finland's Water Pollution Control Program: The Role of Economic Analysis, (PUN 8), IBRD, 1974.

experience in other similar situations is necessary in order that estimates of the willingness of potential beneficiaries to pay connection fees and other sewerage-specific charges can be made. In principle one could impute the value that a householder places upon the connection of his home to a sewerage system from his payment of (a) a connection charge, or (b) a tax, the magnitude of which is in part determined by his connection to a sewer and which could include the additional water charge he is likely to pay. This, however, requires that the householder has an option to connect or not to connect, and therefore to pay or not to pay for the service. If, as is often the case, connection of houses to a sewer placed under a particular street is compulsory for all houses on that street, freely expressed willingness to pay for sewerage is not revealed.

(b) Capital Indivisibility and the Definition of Marginal Cost

For pricing purposes it is important to distinguish between those costs that are a function of consumption and those that are not. Ambiguity in the definition of marginal cost arises where capital indivisibility (or"lumpiness") is present, for, with respect to consumption, costs will be marginal at some times and non-marginal at others. For example, if the safe yield of a reservoir is less than fully utilized, the only costs immediately attributable to additional consumption are certain additional operating and maintenance costs. These are referred to as short-run marginal costs. Long-run marginal costs, on the other hand, refer to the sum of short-run marginal costs and marginal capacity costs; the latter are defined as the cost of extending capacity - for example, building a new reservoir - to accommodate an additional unit of consumption.

The two definitions of marginal cost, one applicable in the short run and the other in the long run, have to be reconciled for a pricing policy which is associated with an optimum use of existing capacity will frequently not be one which results in optimal investment decisions. Strictly interpreted, the marginalist approach requires that price should equal short-run marginal cost when capacity is less than fully utilized, but if demand increases so that existing capacity becomes fully utilized, price should be raised to ration existing capacity. This procedure should continue up to the point where consumers reveal their willingness to pay a price for additional output equal to short-run marginal cost plus the annual equivalent of marginal capacity cost. At this point, that is, where existing capacity is fully utilized and price equals long-run marginal cost, investment in additional capacity is justified. Once the investment has been carried out, however, price should fall again to short-run marginal cost, for the only real costs (or opportunity costs, in terms of alternative benefits foregone) are then operating costs. Price therefore plays the roles of (a) obtaining efficient utilization of resources when operating at less than full capacity, and (b) providing a signal to invest in additional system capacity.

Problems associated with strict marginal cost pricing, as just described, are particularly apparent in the presence of capital indivisibility, a condition typical of water supply projects, where productive capacity is often installed to make up for deficits in current supply and to meet future demands for a number of years hence. Initial costs of constructing reservoirs and laying connecting mains are usually very high in relation to operating and maintenance costs. Strict marginal cost pricing in these circumstances would result in significant fluctuations in price, which in turn would be a source of considerable uncertainty for consumers and which would create problems for planning long-term investment in facilities complementary to, or competitive with, water consumption. Exploitation of groundwater often gives rise to fewer problems of capital indivisibility; in the economist's jargon, the long-run marginal cost curve is frequently relatively "smooth". Even in cases where it is technologically possible to extend capacity in fairly small increments, fluctuations in the availability of finance may mean that capacity is extended in large lumps. This issue is particularly important in less developed countries, where large backlogs in supply may be remedied and excess capacity created at the same time.

Another characteristic of capital indivisibility is demonstrated in an extreme form by a water supply distribution network.1/ Prior to its construction, it is by definition a marginal cost and presumably is a function of the expected consumption of thse benefiting from it. It is, however, normally designed to meet demands placed upon it for many years hence, during which time additional consumption by existing consumers is responsible for negligible additional distribution capacity costs. The pure marginalist approach would suggest that the price charged for this element of a water undertaking's service should also be negligible. It has to be financed somehow, though, and the case is illustrative of the conflict often encountered between economic efficiency and financial requirements.

Many solutions - necessarily imperfect ones - have been proposed to solve the problem of capital indivisibility. They normally define marginal cost more broadly, and set price equal to some estimate of incremental operating and capacity costs averaged over time.2/ Given that numerous alternative definitions have been employed, and that the definitional problem is at the heart of any marginal cost pricing exercise, it is the focus of the subsequent chapters of this paper.

1/ Also by a sewage collection system.

2/ The average incremental cost approach, described in Chapter II, has been widely used in water supply projects in the developing world. See for example, Robert J. Saunders, Bangkok Water Supply Tariff Study, IBRD (PUN 23), June 1976; also Saunders and Warford, Village Water Supply, op.cit, Chapter 7.

(c) Financial Viability and Economic Efficiency

Clearly, marginal cost pricing may not produce a desirable financial performance; significant surpluses or losses may accrue to the utility. A surplus, of course, may be used to defray other public expenditures, or to avoid taxation, and only limited distributional or resource allocation problems would arise.1/ Loss-making, on the other hand, may be attacked on the grounds that those who benefit should pay for a service, even though the expenditure of real resources might have taken place in the past. Moreover, loss-making may entail certain limitations from an efficiency standpoint. First, the accounting losses have to be absorbed somehow, and it will often be difficult to achieve the necessary transfer of real income without creating distortions of consumer or producer's choice as severe as those encountered in deviating from marginal cost pricing. Second, the financial discipline and organizational autonomy resulting from financial viability are often thought to be the best way to ensure efficient operation of the undertaking concerned.2/

Solutions to this dilemma have been proposed which have usually tried to obtain the best of both worlds: the resource allocation advantages of marginal cost pricing on the one hand and the achievement of satisfactory financial performance on the other.3/ There are, in fact, many variations on a common theme, the simplest of which is a two-part tariff where a water consumer would pay a sum per thousand gallons consumed equal to marginal cost, plus a lump sum covering non-marginal "sunk costs" and consumer related costs. In this way, as long as liability to the lump

---

1/ There may, however, be difficulties of the kind experienced in North America in which regulatory commissions invariably place a ceiling upon the return on capital that the utility may earn.

2/ This of course has been a cornerstone of World Bank policy with regard to public utility institution building in the developing world. For a general statement of the issues involved, see Anandarup Ray, Cost Recovery Policies for Public Sector Projects, World Bank Staff Working Paper No.206, July 1975.

3/ See for example: Ronald H. Coase, "The Theory of Public Utility Pricing and Its Application," Bell Journal of Economics and Management Science, Vol. 1, No. 1, (Spring 1970), pp. 113-128.

sum payment does not deter anyone from consuming the system's water altogether, optimal allocation may be achieved. Similarly, efficient allocation may theoretically result from the activities of the imaginary "perfectly discriminating monopolist," who charges each consumer a price equal to the maximum the consumer would pay, on down to the consumer who places a value on water equal to its marginal cost. Although such omniscience is rare, this general approach, popularly known as charging "what the traffic will bear," is often employed to finance water supply; for example, industrial consumers may be charged higher prices than domestic consumers. Even if these methods succeed in achieving efficiency in the short run, however, the justification of additional investment still cannot be signalled without price fluctuations if capital indivisibility is present. Furthermore, the income distribution consequences of charging what the traffic will bear may be perverse.

With regard to waterborne waste disposal, the kind of tariff that would tend to result from application of the above principles is likely to consist of two parts. Since the initial investment in sewerage (primarily sewage collection) is such an important element of costs, and one that may contain the capacity for as much as 25 years' load growth, the associated problems of "lumpiness" or capital indivisibility would normally imply the need for a large fixed charge, plus a relatively low commodity charge. The low commodity charge would be based upon water consumption (and therefore sewage flow), and would reflect incremental operating costs plus incremental capacity costs, mainly of treatment and disposal works.

Since "externalities" are so important in decisions to invest in sewage disposal facilities (see below), there may often be conflict between financial aims of the appropriate utilities and resource allocation objectives. For financial reasons, sewerage authorities frequently have to ensure that high income residential areas - where the need for sewers (and perhaps piped water) is less because of lower population density and the presence of alternative means of disposal (septic tanks) - are served before congested low income areas, where from a general environmental viewpoint, the need is greater. In such cases, the financial viability of the utility requires that individual willingness or ability to pay is given more weight in determining investment priorities than the external effects. Clearly, this may not be an economically efficient ordering of priorities, but due to financial constraints water and sanitation authorities frequently find themselves in such a position.

(d) The Second-Best Problem and Shadow Pricing

Another difficulty encountered in applying marginal cost pricing to the provision of water supplies is known as the second-best problem. What may appear at first sight to be a step in the direction of economic efficiency (for example, setting a price equal to marginal cost, or indeed, of introducing a pricing mechanism where none hitherto existed) may not be an improvement at all should inefficient conditions prevail in other sectors of the economy. Optimality in any one sector might require a price greater or less than marginal cost to counter such inefficiencies.

In practice, in any economy in which there is a reasonable degree of competition, it has to be assumed that elsewhere goods and services are sold at prices that in general approximate their marginal costs. If not, the difficulties of adjusting for all imperfections would lead to the nihilistic conclusion that there are, after all, no empirical grounds for preferring any one set of pricing rules over any other. Where, however, goods or services that are in direct competition with (or are complementary to) the services in question are priced in a way that diverges sharply from the standard set for the water supply or sewage disposal system, it may be necessary and feasible to make some adjustment. Thus, if prices of resouces employed in constructing and operating water supplies diverge from their marginal cost to society, shadow prices should ideally be placed upon them in evaluating the real cost to society of the expenditure. Labor that would otherwise be unemployed might be valued near zero (that is, at an estimate of its opportunity cost) even though, due to market imperfection, it is able to command a wage rate in excess of the minimum amount needed to attract it; foreign exchange costs should be valued at their market rate; interest rates should reflect the social opportunity cost of capital, and so on. Adjustments of this nature are necessary if the ultimate consumer is to be faced with a price for water that reflects the true conomic cost which his consumption entails.[1]

(e) Externalities and Consumer Knowledge

There may be reasons why the observed willingness of consumers to pay should not be relied upon as the sole criterion for supplying them with water or sewerage facilities. There is for example the argument that externalities are sometimes associated with such services. Thus, an external benefit that might result from the consumption of potable water is that the health of X might improve because he makes use of an improved supply, and as a consequence, X may not infect Y whose future health would also improve. However, since X would not take the health of Y into account in his decision to consume potable water, his willingness to pay would tend to understate the benefits that would accrue to the community as a whole. Another argument is simply that water consumers may

---

[1] For a comprehensive treatment of the use of shadow pricing in project evaluation, see Lyn Squire and Herman van der Tak, Economic Analysis of Projects, Baltimore, The Johns Hopkins University Press, 1975.

not sufficiently understand the relationship between improved water supply and health:[1] the assumption of a well-informed consumer is essential if normative judgements are to be made about the expression of his willingness to pay.

The externality problem with regard to sewerage is particularly complicated. In viewing it, it is important to distinguish between sewage collection and disposal. There is presumably, no reason to expect willingness to pay to be expressed for sewage treatment and disposal facilities which are often several miles from the properties that are connected to the sewers. Indeed, investment in treatment and disposal is largely designed to be of benefit not only to the producer of the waste, but also to others in the vicinity. Since the discharge of waste and excreta creates costs to parties other than the waste producer, any method of pricing or project evaluation that is restricted to measuring the benefits to the waste producer on the one hand, and the costs of sewerage facilities on the other, ignores a critical aspect of the problem. Theoretically, any charge for waste water disposal should be related to the marginal resource cost of disposal less the marginal cost savings (benefits) to other parties because of the facilities provided. Put another way, benefits of sewerage facilities consist of benefits accruing to waste dischargers (who might reveal their willingness to pay directly through sewerage charges), plus benefits to other parties (for example, savings in water supply treatment costs, reduced medical expenditures, reduced smell, etc.).

1/ The fact is that no one - even the experts - precisely understands the relationship between improved water supply and health. See: Measurement of the Health Benefits of Investment in Water Supply, (PUN 20), Energy, Water and Telecommunications Department, World Bank, January 1976 and Saunders and Warford, Village Water Supply, op.cit.

In practice, the actual benefits of an improved sewage collection and disposal system may simply be aesthetic in nature, or there might be health, land value, recreational, or cost savings benefits. Unfortunately, as noted earlier, these are rarely quantifiable. Presumably, the health impact of improved sewerage facilities will tend to be greater in the more densely populated urban areas because of the lack of unpolluted water supply and the greater chance of contagion. On grounds of externalities, and also because, in general terms, consumers are often unaware of the advantages of clean water in improving health, this may point to a policy of subsidizing basic sanitation facilities in such areas, and this of course is often done.

A related issue concerns the appropriate way to charge for water supply and sewerage in cities in which some areas are served with water supply only while others have both water and sewerage. The most common means of dealing with this situation, where water and sewerage systems are operated by the same authority is to separate the costs of water supply and sewerage, and to charge households consuming only water for that water, with a sewerage surcharge only for those households actually connected to the sewerage system.

Such a policy will often be suboptimal in terms of the criterion that price should equal incremental costs. For those already connected to the sewerage system, the incremental costs of waste disposal are relatively low (since the main element of costs - i.e. the sewers themselves - are "sunk"). It can be expected, as long as the original decision to invest in sewerage for that group was correct in the sense that the economic benefits of the project exceed its costs, that the marginal social cost of the consumption and disposal of water by some of those currently without sewerage will exceed that of those who are connected, because of the magnitude of the externalities created. Theoretically, therefore, there may sometimes be a case for levying a metered water charge for persons without sewerage facilities that is greater than for those who have sewerage facilities. Clearly, the social/political obstacles to such a policy would be immense, but the general rationale is sometimes used to justify some contribution to sewerage costs from those who do not directly receive this service.

(f) Metering

Implementation of use-related pricing (through metering) for water supply is expensive, and its introduction or continuation should ideally be subject to cost-benefit analysis. The benefits of metering are the cost savings brought about by reducing consumption. Savings may be achieved by deferring investment as well as by reducing annual operating and maintenance costs. To determine whether the investment in metering is worthwhile, the present worth of these savings should be compared with the present worth of initial and annual costs of metering plus the reduction in the value of water consumed. Because the reduction in consumption likely to result from metering is normally highly conjectural, one way to approach the problem is to ask the question, what percentage reduction in consumption would justify the introduction of metering? If extreme values result from such a calculation, it is easy to make a judgement as to whether or not metering is justified; if not, at least major errors in installing meters may be avoided.[1/]

1/ For some practical applications of this principle, see Richard N. Middleton, Robert J. Saunders and Jeremy J. Warford, The Costs and Benefits of Water Metering, (PUN 29) Energy, Water and Telecommunications Department, IBRD June 1977; Jeremy J. Warford and Ralph Turvey, Lahore Water Supply Tariff Study, (PUN 12) Public Utilities Department, IBRD, 1974; and Robert J. Saunders, Bangkok Water Supply Tariff Study, (PUN 23) Energy, Water and Telecommunications Department, IBRD 1976. Note that similar principles apply to the use of other devices to regulate the consumption of water, such as guards at public standposts. See Saunders and Warford, Village Water Supply, op.cit.

(g) Temporal and Locational Variations in Costs

The marginal cost pricing principle implies that price should reflect variations in the cost of supplying water to different consumers. It may therefore be desirable to distinguish between consumption at different times and at different locations. In the case of water supply, the cost of consumption may sometimes be expected to vary seasonally. If so, whether pressure on capacity is due to demand peaks or supply troughs or both, there may be a case for varying the price of water to achieve an efficient allocation of supplies.[1/] Theoretically, unless capacity is fully utilized during the off-peak period as well as during the peak the rule should be that off-peak users pay just for short-run marginal costs (operating costs) while peak users pay for all marginal capacity costs plus the marginal operating costs incurred during the period. Consequently, additional storage capacity necessary to satisfy the excess of peak season over slack season demand should be constructed as a result of a revealed willingness of consumers to pay the extra amount for water during the peak demand season. In practice, it would only be possible to introduce differential pricing for seasonal peaks: the need to meet diurnal peaks is reflected in the design of distribution systems, and differential pricing here would, *prima facie*, be too expensive to administer.

Geographical variations in marginal costs - if sufficiently large - should also be reflected in pricing policy. The use of national or state-wide uniform tariffs, which in developing countries is fairly widespread and seems to be growing, is clearly at odds with the principle, and may be responsible for inefficient locational decisions, particularly by large water-using industry.[2/] Occasionally,

---

1/ The application of peak load pricing to water supply is best described in J. Hirshleifer, J. de Haven and J.W. Milliman, *Water Supply: Economics, Technology and Policy*, University of Chicago Press, 1960.

2/ The inefficiencies involved in such a policy have been pointed out by World Bank staff many times. The argument is presented more fully in Saunders and Warford, *Village Water Supply*, op.cit.pp. 176-179.

there may also be scope for distinguishing between consumers within a given urban area: connection and distribution costs may vary with population density, while consumption costs (pumping, etc.) may vary according to terrain.

A number of political and social difficulties arise when attempts are made to ensure that temporal and locational variations in costs are reflected in pricing policy. In many cases, because the "need" for water is more apparent during the dry season, it is particularly difficult to levy a surcharge on consumption at that time. Regarding geographical cost variations, one explanation for the increasing pressure for uniformity is the improvement in communication which allows people in various parts of the country to know what is going on elsewhere.

(h) Supplying the Poor

In order to ensure that the poor obtain a minimum adequate supply of water and/or adequate waste disposal facilities, it may be desirable to modify the marginal cost pricing approach.[1/] This can be done by means of a tariff schedule that consists of two steps - a low subsidized "lifeline" rate for the first 6 to 8 cubic meters per month and a charge equal to marginal cost for all additional consumption. This will normally provide an acceptable tradeoff between efficiency[2/] on the one hand and equity on the other.

Tariff schedules with multiple increasing blocks or with blocks which are intended to increase approximately in proportion to the recorded income distribution of the country are relatively common in developing countries but, while they

---

1/ More direct methods are of course used; provision of communal standposts is a feature of most water supply systems in developing countries.

2/ Given the presence of health externalities there may also be efficiency reasons for subsidizing minimum amounts of consumption for low income consumers.

may often be the best that can be achieved in a political sense, are not an entirely satisfactory solution.[1] In many developing countries households with house connections represent a relatively wealthy segment of the population, and there is no good reason for pricing that portion of their consumption which is in excess of the basic minimum at less than marginal cost. There are moreover many influences on water consumption other than income, a reliable correlation between water consumption and household per capita income being particularly difficult to establish. Given that if a government seeks to redistribute income there are many more efficient ways to do it than through water supply tariffs, it would seem that a two step tariff which emphasizes allocational efficiency by equating the top step to marginal cost would best focus on the one aspect on which tariffs can have a significant impact.[2]

3. Summary

In the preceding sections a number of problems of implementing marginal cost pricing in the water and sewerage sector have been discussed. In brief, the efficiency objective, which requires, inter alia, consideration of externalities, geographical and locational cost variations, and compensation for market failure, has to be reconciled with a number of other objectives of pricing policy. These include equity (primarily to ensure that the poor are not denied minimum levels of service), ease of administration (which implies considerable price stability and

---

1/ A recent survey of World Bank projects shows that out of the 36 borrowers which have metered water supplies, 21 have increasing block rates for domestic consumers. However, such a policy is generally an improvement over the declining block rate still advocated by the American Water Works Association and normally used in the USA. A recent survey of the tariff structures used by over 70 different American utilities showed that more than eighty percent of the tariff structures contained decreasing-block water charges. See: Helt, A. and D.L. Chambers, "An Updated Hartford Metropolitan District Water Rate Survey," Journal of the American Water Works Assn. August 1976, pp.426-430. With the rare exceptions in which economies of scale are encountered on a per consumer basis, the only rationale for such a policy might be if the initial high blocks covered consumer-related costs such as meter reading. Fortunately such declining block tariff structures are now rarely encountered in developing countries.

2/ Of course subsidized connection costs which enable low income consumers to secure house connections can result in transfers of real resources in developing countries.

the evaluation of metering policy), and the financial viability of the water and sewerage authority itself.

It is apparent from this necessarily superficial survey of the issues, that the way in which this complex set of objectives and constraints is handled in any particular circumstance depends upon the way in which marginal costs are perceived. For example, the concept of the two part tariff, which may be invoked to reconcile efficiency objectives with financial goals or income distributional criteria, implies a definite distinction between the costs that are marginal with respect to consumption and those that are not, and/or between sunk costs and marginal costs. The metering decision also depends upon such a distinction,and so should an analysis of the costs of extending service to different categories of consumers.

The conclusions that may be reached on these important policy issues may therefore differ significantly to the extent that there are different interpretations of marginal cost. However, in practice, due partly to different perceptions of the objectives of pricing policy, a number of somewhat different definitions are in common use. It is the intention in the remainder of this paper to analyse several of the most widely used definitions in order to suggest the appropriate methods to adopt for the water and sewerage sector, in which significant capital indivisibilities are frequently present.

II. Alternative Definitions of Marginal Cost

In the following sections marginal-or incremental-cost is defined in four slightly different ways. The definitions are similar in that they are forward looking, i.e. they consider only future costs and future output. The definitions differ in the extent to which they stress the importance of short-run as opposed to long-run costs, operation as opposed to investment costs, and changes in consumption in different time periods. In consequence, when used for pricing purposes they vary in the extent to which they focus on short versus long run allocative efficiency, and the extent to which they attempt to minimize price fluctuations in the presence of lumpy investments. The four definitions examined are:

1. "Textbook" Marginal Cost (TMC)
2. "Textbook" Long Run Incremental Cost (TLRIC)
3. Present Worth of Incremental System Cost (PWISC)
4. Average Incremental Cost (AIC)

1. "Textbook" Marginal Cost

Marginal cost can be defined as the first derivative of total cost with respect to output, where TC=f(Output) is a continuous single-valued monotonic function. When, however, a total cost function is discontinuous (investment is lumpy or cost records are kept on the basis of yearly changes and not by changes for each additional unit), the above definition is not strictly applicable. In such cases there is considerable ambiguity in economics literature about how to choose the appropriate magnitude of output change, and about the appropriate cost which should be attributed to that output. It is possible, for example, to argue that the total cost of an additional lump of investment should be attributed to the very last unit of output. Such an interpretation, however, can be opposed on the grounds that additional investment is justified when consumers show their willingness, over a given period of time, to assume the financial (and presumably economic) burden of additional capacity investment measured over the same period.1/ This burden can be defined as the payment that has to be made in order to cover the operating and amortization costs of the additional capacity. In practice it is inconvenient to use instantaneous increments, and amortization schedules broken up into minute time periods, and in our definition of TMC we use periods of one year for these purposes.

Of course if cost-benefit analysis is feasible the problem of deriving an investment-signal price can be avoided. Then, in cases when investment is lumpy, price is set equal to short run marginal cost, and when excess capacity nears exhaustion a cost-benefit exercise is undertaken to see if additional investment is justified. If it is found to be justified, the investment is undertaken and price is then set equal to the new short run marginal cost. 2/ If, however, investment is not shown to be justified at that time, presumably price would be allowed to rise in order to allocate the perfectly inelastic supply. In this circumstance the behavior of price would correspond closely to the TMC definition outlined below. Of course, as discussed in Chapter 1 of this paper, the difficulties of benefit measurement related to public utility output generally preclude the option of short run marginal cost pricing with cost-benefit analysis justifying additional investment.

1/ See J. J. Warford, "Water Requirements: The Investment Decision in the Water Supply Industry," Manchester School of Economic and Social Studies, Vol. 34, (January 1966), pp. 87-106.

2/ This alternative might be appropriate in the evaluation of certain highway projects. See A. A. Walters, The Economics of Road User Charges, World Bank Staff Occasional Papers, No. 5, 1968.

The TMC definition of marginal cost examined in this paper generally reflects micro-economic pricing theory, with the modification that each increment is taken to be the change in output which occurs during one year. 1/ As a result TMC makes use of two concepts, i.e. short-run marginal cost (SRMC) which reflects increments in operating and maintenance costs brought about by increases in output, and marginal capacity cost (MCC) which reflects increments in capital expenditures (capacity) which are necessary to increase output. Since these cost and output increments are considered only one year at a time, the TMC definition reflects a relatively short time horizon.

TMC is defined as:

$$TMC_t = SRMC_t + MCC_t$$

$$= \frac{R_{t+1} - R_t}{Q_{t+1} - Q_t} + \frac{rI_t}{Q_{t+1} - Q_t}$$

where t = Year for which TMC is being calculated

R_t = Operation and maintenance expenditures in year t

Q_t = Water produced in year t

I_t = Capital expenditures in year t

r = The capital recovery factor, or the annual payment that will repay a $1 loan over the useful life of the investment with compound interest (equal to the opportunity cost of capital) on the unpaid balance. 2/

1/ Our definition of TMC is therefore somewhat arbitrary with regard both to the magnitude of the increment in output and the application of an amortization factor to capital costs. Even the textbook definition, as we define it, therefore makes use of some "smoothing." Definitions which fail entirely to do so, we would argue do not deserve to be considered seriously as practicable alternatives.

2/ $r = \frac{Ii\,(1+i)^n}{(1+i)^n - 1}$

where I is the investment cost, i is the appropriate interest rate, and n is the useful length of life of the investment (assumed to be 30 years).

Given the fact that when capacity is reached, there could be a vertical gap between SRMC and TMC, for purposes of our subsequent analysis the increment in consumption used to calculate the MCC part of TMC is that for the year immediately following the expenditure on new investment and not for the year before the expenditure.1/

With a lumpy investment stream, TMC for the years in which capacity expenditures take place reflects both SRMC and MCC; during years in which no capital expenditures take place TMC equals SRMC only. Charging according to TMC, therefore, involves significant fluctuations in price, the signal to invest in additional capacity being given when output is at capacity and the price paid by water consumers is equal to short run marginal cost plus annual equivalent marginal capacity cost (MCC).

2. "Textbook" Long Run Incremental Cost

Use of the TLRIC definition of marginal cost emphasizes the need to give investment signals to present and potential water consumers at the expense of some loss in short run allocative efficiency. As normally presented in the literature, the forward looking time horizon of TLRIC does not, however, extend beyond the next investment.2/ TLRIC is defined as follows:

1/ A problem with the use of this definition in subsequent analysis is that if the price elasticity of demand is different from zero (and there is considerable evidence to suggest that in most cases it is), the consumption (and output) of water would increase more rapidly (assuming demand at a given price is growing at some compounded rate) during years when there is large excess capacity, and less rapidly in years when the utility is approaching capacity and short run marginal costs are rising. As a result, the TMC estimate of SRMC, which we later on assume to be increasing at the same rate as output, could in reality be an underestimate as output nears the capacity of the utility.

2/ Of course TLRIC could be redefined to look at the average of the next several investments or at one particular "representative" future investment.

$$TLRIC_t = \frac{R_{t+1}-R_t}{Q_{t+1}-Q_t} + \frac{rI_k}{Q_{k+1}-Q_k}$$

where the notation is identical to that used for TMC with the exception that k denotes the year in which the very next major investment expenditure is completed.[1] As a result, during the years t through k the term $rI_k/Q_{k+1} - Q_k$ remains constant, reflecting the annual equivalent of marginal capacity cost for the next lump of investment. In year k+1, after investment has taken place in year k, k is redesignated to be the new next year in which a large investment is completed, and, again, over the period t through k the term $rI_k/Q_{k+1} - Q_k$ remains constant, reflecting the annual equivalent of marginal capacity cost for the next lump of investment. For years in which investment takes place, TLRIC will equal TMC.

The TLRIC definition jumps from investment peak to investment peak with price changing immediately following an investment to reflect the incremental costs of the next big capacity investment which will have to be incurred. This method or close variants of it have been most frequently used in the electric power sectors where the need for forward looking investment signals is critical, and where because of the existence of interconnected nationwide grids, lumpiness in investment is less of a problem.[2]

3. Present Worth of Incremental System Cost

PWISC is another method of defining marginal cost which emphasizes the necessity of providing consumption and investment signals which reflect

---

1/ For ease of exposition a construction period of one year is assumed.

2/ The TLRIC method is described in Ralph Turvey and Dennis Anderson, Electricity Economics: Essays and Case Studies, (Baltimore: Johns Hopkins University Press, 1977).

the magnitude of forthcoming investment. As presented by Turvey,[1] the PWISC definition does not, with the exception of replacement costs, look beyond the next lump of investment, and therefore also tends to ignore the effect of increasing or declining unit costs associated with subsequent increases in output and consumption. For purposes of water supply pricing PWISC is defined as: the present worth of the increment of system costs resulting from a permanent increment in consumption at the beginning of year t minus the present worth of the increment of system costs resulting from the same permanent increment in consumption starting at the beginning of year t+1. Algebraically, this can be expressed as:

$$PWISC_t = \frac{(R_{t+1} - R_t) + \left[\frac{I_k}{(1+i)^{k-t}} - \frac{I_k}{(1+i)^{k+1-t}}\right] + \left[\frac{I_{k+29}}{(1+i)^{k+29-t}} - \frac{I_{k+29}}{(1+i)^{k+30-t}}\right]}{Q_{t+1} - Q_t}$$

where the notation is similar to that used for TLRIC in that k again denotes the year in which the very next large investment expenditure takes place (the year in which the system reaches capacity), where i is the opportunity cost of capital, and where the useful life of investment is assumed to be 30 years.

4. Average Incremental Cost

The AIC definition of marginal cost represents an attempt to (a) compromise between short run allocative efficiency goals and the need to signal the justification of investment in additional capacity, and (b) look

---

1/ Turvey has proposed slight variants of the PWISC definition in several sources. The source on which we relied most heavily is: Turvey, Ralph, Optimal Pricing and Investment in Electricity Supply, (London: George Allen and Unwin Ltd., 1968), p. 55. In this source, there is an implied assumption that investments take place in every year, although PWISC may, of course, be defined in terms of any postulated increment of output.

beyond the traditional economic definiton of the long run by including all future investment costs during a specific time period; usually 10 to 15 years would be the maximum period for which reliable data would be available. In looking beyond the next increment in capacity, AIC makes different assumptions about the proportion of the investment which must be paid at one point in time in order to reveal consumer willingness to pay, and about the relevant magnitude of the next increment in capacity, which is invariably difficult to specify, particularly in large and complex systems in which many investments (some of which produce joint products) are taking place simultaneously.

Basically AIC assumes that in cases when investment is lumpy, marginal capacity cost (MCC) can best be estimated as:

$$MCC = \frac{\text{Present Worth of the Least Cost Investment Stream}}{\text{Present Worth of the Stream of Incremental Output Resulting from the Investment}}$$

Thus, if at any point in time consumers willingly pay a price equal to incremental operating costs plus MCC as defined above, this is an indication that the benefits of the investment program, which can include one or more projects and which would be measured in cost benefit analysis as the present value of total revenue (PxQ), are at least equal to the costs, measured as the present value of the stream of costs to be incurred through time. The average incremental cost estimate which we simulate is calculated by discounting all incremental costs which will be incurred in the future to provide the estimated additional amounts of water which will be demanded over a specified period, and dividing that by the discounted value of incremental output over the period, i.e. 1/

1/ As noted in Chapter I, the AIC definition of marginal cost is widely used in World Bank water supply projects. The same concept, known as "discounted unit cost," is employed in official discussions on water pricing in the UK. See Paying for Water, National Water Council, London, April 1976.

$$AIC_t = \frac{\sum_{\hat{t}=1}^{T} \left[\frac{(R_{t+\hat{t}} - R_t) + I_{t+\hat{t}-1}}{(1+i)^{\hat{t}-1}} \right]}{\sum_{\hat{t}=1}^{T} \left[\frac{(Q_{t+\hat{t}} - Q_t)}{(1+i)^{\hat{t}-1}} \right]}$$

where the notation is similar to that used previously except that T is the number of years for which water expenditures and attributable output are forecast and over which price is being smoothed. Theoretically, the interest rate (i) in the numerator of AIC should be set equal to the opportunity cost of capital, while that in the denominator should be equal to the time preference rate for consumption, reflecting the assumption that consumption today is more valuable than consumption in the future.

The AIC definition gives marginal cost estimates which smooth out lumps in expenditure streams while at the same time reflecting the general level and trend of future costs which will have to be incurred as water consumption increases. Where unit costs are lumpy, the AIC estimate will never be equal to the TMC estimate; it will always be above SRMC and usually below TLRIC,[1/] and relative to TMC will therefore tend to discourage "justified" consumption when there is excess capacity and to provide premature investment justification signals as capacity reaches full utilization.

5. The Choice of Definitions

In the abstract, marginal cost (the change in total cost brought about by an infinitesimally small change in output) is a simple concept. In

---

1/ AIC can exceed TLRIC in cases where investment is smooth, and where capacity costs are rising rapidly and the incremental costs of subsequent investments are much larger than those of near term investment.

practice, however, where we are dealing with changes in both costs and output through time, many different forward looking definitions of marginal cost are employed. The version actually selected may depend upon:

(a) The size of the increment in output which is being examined;

(b) The length of the time horizon which is considered to be relevant, or the period of time for which significant excess capacity will exist;

(c) The desired emphasis on near term allocative efficiency versus longer term resource allocation;

(d) How rapidly changes in technology, or economies of scale are expected to significantly affect production costs;

(e) The extent to which relative price stability through time is thought to be necessary; and

(f) Revenue implications.

The four definitions examined in this paper generally cover the spectrum of ways in which most of these factors can be traded off with each other. Of these methods, TMC is the one that adheres most strictly to the real marginal costs that are actually incurred at any one point in time although as noted previously the actual magnitude of TMC is dependent on assumptions concerning the appropriate output increment and the proportion of capacity cost which must be covered in order for consumers to reveal their willingness to pay. Furthermore, even with the moderate "smoothing" that the TMC definition incorporates, in view of its implications for price fluctuations when investments are lumpy, its practical application has been questioned by many economists.1/

To remedy this price fluctuation deficiency, and to address the fact that present and potential water consumers have imperfect information about future water prices, it is necessary to incorporate marginal capacity costs in prices even when investment in capacity is not imminent. A number of alternatives for doing this have been proposed. PWISC, while recognizing the concept of marginal capacity costs, does so in such a way that considerable price fluctuation remains, price falling significantly following an investment, and rising gradually to approximate TMC and TLRIC at the point at which the next investment is due. PWISC, TLRIC and TMC therefore adequately signal the need for investment in capacity, but only TLRIC avoids the significant drops in price that are associated with the other two methods at times of temporary excess capacity. Indeed, TLRIC implies relatively stable prices between investments, significant changes taking place only immediately after an investment has taken place.2/

AIC is distinguished from the other three definitions in that it takes a longer view of costs, looking beyond the next increment in capacity. This can be particularly important where rapid technological change is taking place or significant scale economies are being experienced. AIC also has the attribute of avoiding severe price fluctuations although it does not adhere closely to TMC either at capacity points (as do TLRIC and PWISC) or during periods of excess capacity. It is thus essentially a compromise

---

1/ For a notable exception, see Hirshleifer, de Haven and Milliman, Water Supply: Economics, Technology and Policy, op cit, p. 98, who dismiss objections to price fluctuations as "prejudice."

2/ No change takes place in the constant cost case.

solution, neither adequately (in a textbook sense) signalling the justification for any one specific investment in a program, nor corresponding to the textbook SRMC ideal in the short run.

Other definitions which are variations on the above basic themes are, of course, possible. We have specified and simulated a number of these, including several which were derivatives of AIC and PWISC, TMC, and AIC and TLRIC. Our conclusion was that for water supply pricing, the four basic definitions indicated above adequately represent the spectrum of alternatives.

6. Cost Streams and Simulation

The four definitions of marginal cost are simulated for nine different cost-output combinations. The nine combinations are most easily viewed as consisting of three different cases (A through C), each of which assumes different rates of growth for investment, and for operating costs and output. The three cases also involve simulations of three different investment streams, each of which has different properties with regard to phasing, and lumpiness. The three cases are summarized in Table 1 which presents the various assumptions made about annual growth rates for investment, and for operating costs and output.

The expenditures which are included in the cost streams are assumed to be only those which are relevant for pricing purposes, i.e., costs which through time are a function of consumption, and which have been adequately shadow valued to reflect resource opportunity costs. Also all costs are assumed to be in constant prices and to include no amounts for interest, direct or indirect taxes, and other transfer payments. For purposes of the simulation exercise, the feedback from the defined marginal cost to price

Table 1

COMBINATIONS OF EXPENDITURES AND OUTPUT WHICH ARE SIMULATED

Investment Cost Behavior 1/		Investment Expenditure Stream Characteristics: Degrees of Investment Lumpiness	Investment Expenditure Stream Characteristics: Yearly Rate of Increase in Total Investment Expenditures (%)	Yearly Rate of Increase in Operating Costs and Output 2/ (%)
Case A Increasing Unit Investment Costs	1.	Investment at 10 yr Intervals	10	2
	2.	Investment at 5 yr Intervals	10	2
	3.	Investment Takes Place Each Year	10	2
Case B Constant Unit Investment Costs	4.	Investment at 10 yr Intervals	5	5
	5.	Investment at 5 yr Intervals	5	5
	6.	Investment Takes Place Each Year	5	5
Case C Declining Unit Investment Costs	7.	Investment at 10 yr Intervals	2	10
	8.	Investment at 5 yr Intervals	2	10
	9.	Investment Takes Place Each Year	2	10

1/ The fact that investment costs per unit increase, decrease or remain constant can be seen by comparing the last two columns in this Table.

2/ For purposes of simplicity, it is assumed that operation and maintenance costs and output vary together.

and thence to quantity demanded is not taken into account. In effect, this assumes perfect inelasticity of demand over the relevant price ranges. This assumption is convenient in highlighting the consequences of various definitions of marginal cost, although if true in practice, it would make marginal cost pricing irrelevant for resource allocation.

In the simulations the discount rate used for the opportunity cost of capital in both AIC and PWISC, in specifying the capital discount factor r, and the discount rate representing the consumption time preference rate in AIC, is 10 percent. Higher and lower discount rates were simulated but the results of the comparative analysis were not significantly affected. The value of r is 0.1061; this corresponds to a thirty year capital recovery period, which is assumed to be the average useful life of water supply investments. While surface water installations with large civil works components may have much longer useful lives, some groundwater investments, more oriented toward pumping equipment, tend to have a shorter life.

All expenditure and output streams are specified (forecast) for a period of 50 years. The simulations discussed in this paper are of estimates of each of the four definitions for each of the first 25 years of the 50 year cost-output streams and for the nine different cost-output combinations considered.

7. Criteria for Evaluation

The results of the marginal cost definition simulations are compared on the basis of (a) which of the three alternative definitions deviate least from TMC, and under what conditions, (b) which of the four definitions entail the least price and revenue variability (which best smooth out investment lumps), and (c) how each of the four definitions compare with regard to the total amount of revenue they generate.

The basis on which deviations from TMC are compared is that TMC approximates the generally accepted theoretical specification of marginal cost as well as any of the methods, although as noted previously, overall economic efficiency may require, as a basis for pricing, a smoothing out of incremental costs and a time horizon which extends beyond the next increment in investment. In other words although TMC is used as a base for statistical comparison, its use as such is not intended to imply that it is necessarily the theoretically "best" definition. Absolute deviations from TMC are calculated for each of the 25 years for which marginal cost estimates are made, and ratios of the alternative estimates to TMC are calculated and compared.

The examination of price and revenue variability is carried out by plotting the path of the marginal cost estimates over 25 years, and by examining and comparing standardized ranges and indexes of variability for each of the four definitions and nine cost-output combinations. Indexes of price and revenue variability are derived by comparing the deviations of revenue and price generated by each definition from a general trend line representing price and revenue through time. The trend lines about which price and revenue variation are measured are derived by least squares regressions of total revenue (or price) on time for each simulated total revenue (price) stream. The trend equation specified is of the form $TR=a+bt+ct^2$ where TR is Total Revenue (or price), and t represents time moving from 1 to 25. Deviations about this line are compared by examining the ratio of unexplained variation to total variation.

Estimates of the revenue generation implications of each method are of course straightforward, given the assumption already referred to. of perfect inelasticity of demand.

III. The Simulation Results

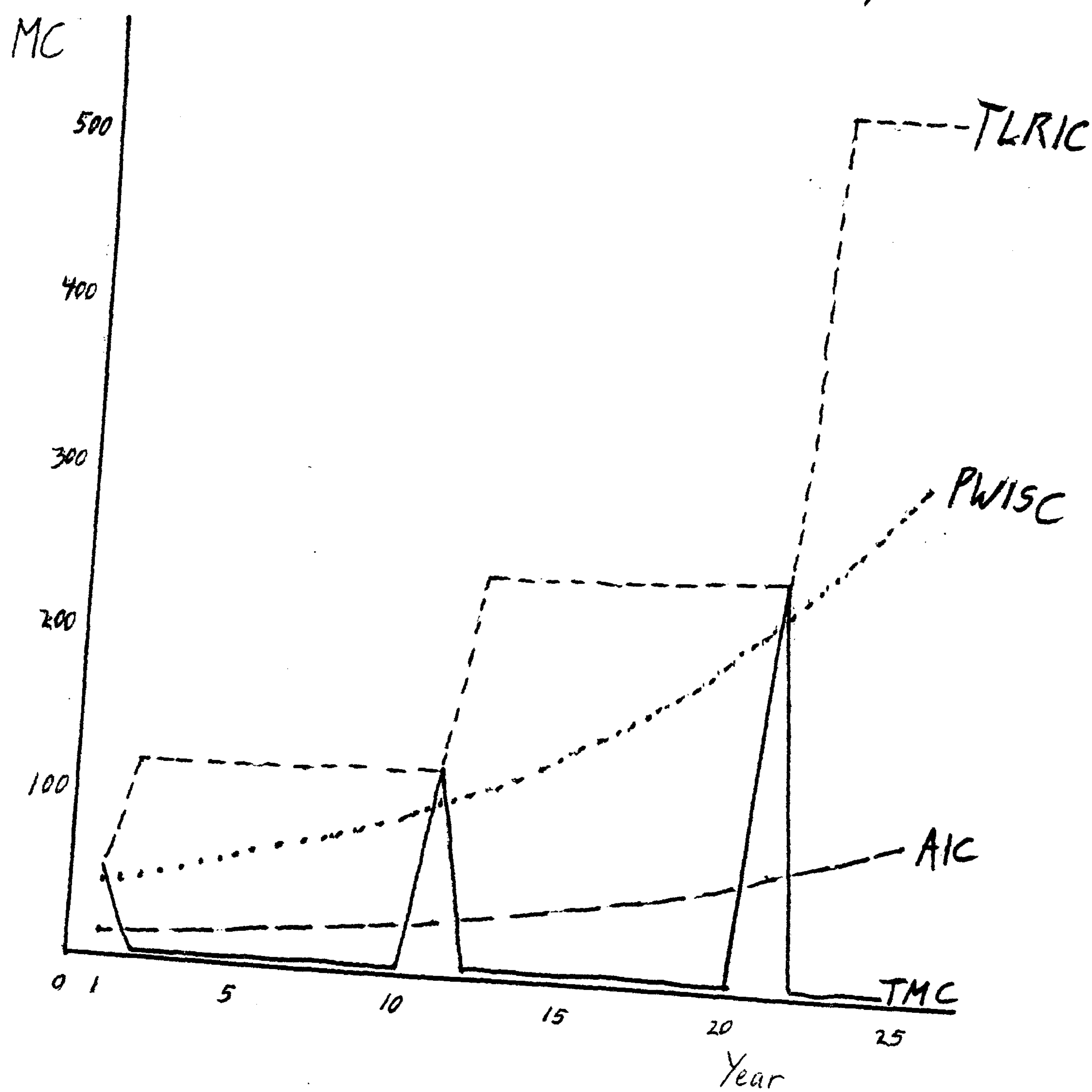
This chapter presents highlights of the simulations of the four marginal cost definitions on nine of the cost-output combinations. The primary emphasis is on comparing how the price estimates behave under conditions in which investment is lumpy. Behavior is judged on the basis of price and revenue fluctuation, revenues generated, and deviations from narrowly defined economic efficiency. A listing of the hypothesized cost streams and a more complete enumeration of the results of all of the simulations are contained in Annexes I, II and III.

1. Price and Revenue Fluctuation

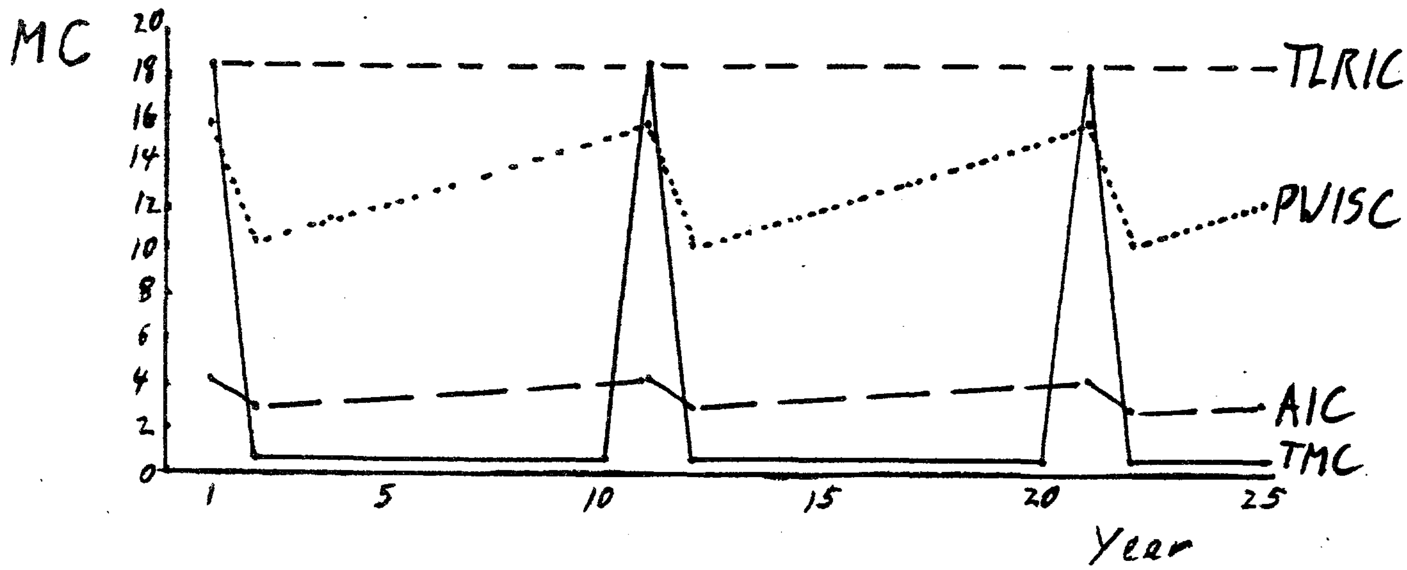
As outlined in Chapter I, a major reason marginal cost has in many cases not been adopted as the basis for public utility pricing is that in cases in which investment is lumpy, the resultant price would be extremely volatile, generating both political and financial management problems for the utility. The fact that the TMC definition is particularly volatile can be seen in Graphs 1, 2 and 3, which show plots of the four definitions simulated for the lumpy investment stream (investment every 10 years) in the increasing, constant, and declining cost cases.

In the increasing cost case (Graph 1), which is the most common in water supply, it can be seen that both AIC and PWISC show virtually no volatility about their trend lines while TLRIC exhibits significant discontinuities at each investment point. In the constant cost case (Graph 2) TLRIC shows no significant price variation while both PWISC and AIC show some variation; although significantly less than TMC. In the declining cost case TMC is again the only definition which shows great price volatility. It is followed in order of volatility by TLRIC, PWISC and AIC, the latter being quite stable over time.

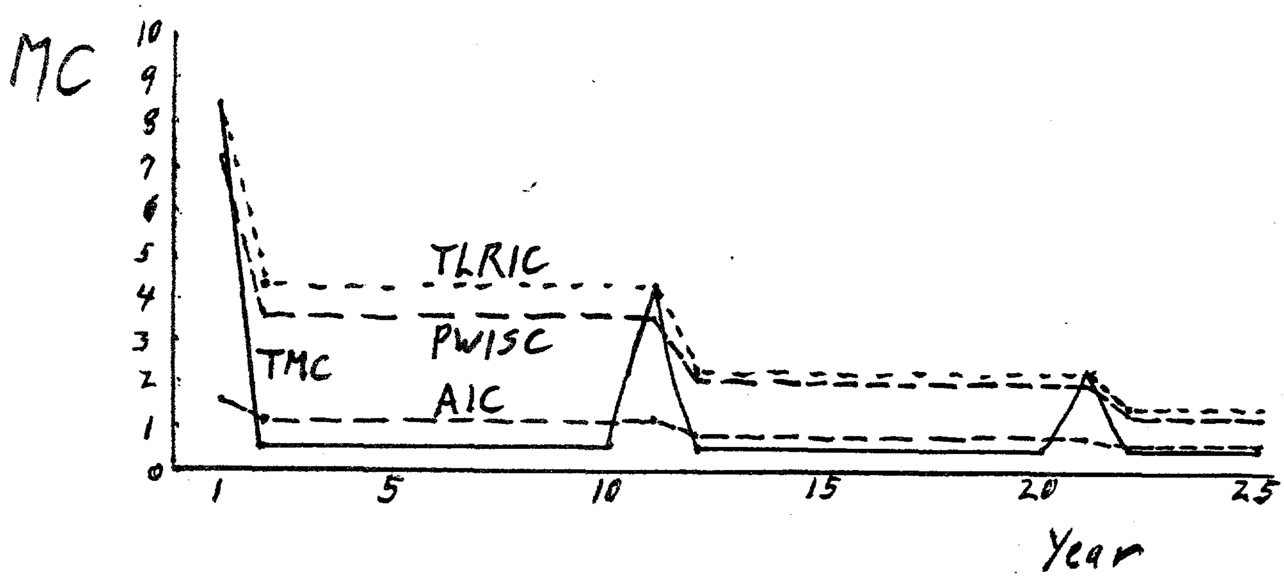
GRAPH 1
CASE A - Investment Every 10 Years



GRAPH 2
CASE B - Investment Every 10 Years



GRAPH 3
CASE C - Investment Every 10 Years



As might be expected, revenues generated by the four price definitions exhibit relatively the same volatility characteristics as do prices. In the increasing and decreasing cost cases AIC generated the least volatile revenue estimates followed closely by PWISC. In the constant cost case TLRIC revenues are the least volatile, while PWISC revenues are slightly more volatile than those generated by AIC.

Tables 2, 3 and 4 present the results of attempts to derive summary numerical measures of the relative price and revenue variability of the four definitions. The measures presented are imperfect in that the indexes of variation in Tables 2 and 3 are somewhat dependent on both the form of the function fitted, and on the extent to which a trend is present about which to measure variation. The standardized ranges on the other hand, reflect only differences in the years of maximum and minimum cost. Nevertheless, these numerical measures together with the graphical illustrations, consistently indicate that, as expected, the three alternative marginal cost definitions exhibit considerably less price and revenue volatility than does TMC. Of them all, AIC is generally the least volatile, although TLRIC is superior in the constant cost case.

2. Economic Efficiency.

Under the assumption that TMC represents a reasonable approximation of a pricing policy which encourages an efficient allocation of resources in the short run, and which automatically signals the justification of each additional investment, deviations of the three alternative definitions from TMC are assumed, for purposes of the simulation exercises, to represent deviations from an efficient pricing norm. As noted previously, reservations may be expressed as to the use of TMC in this way. TMC is not necessarily an absolutely accurate representation of marginal cost as defined in economic theory. In calculating TMC important assump-

Table 2

INDEXES OF REVENUE VARIATION WHEN INVESTMENT OCCURS ONCE EVERY TEN YEARS[1/]

CASE	TMC	TLRIC	PWISC	AIC
A	98	12	1	0
B	99	0	14	10
C	76	27	23	1

1/ Larger indexes represent greater variation about a trend line. The trend line was estimated by a least squares regression of the form $TR = a+bt+ct^2$ where TR is total revenue and t is time going from 1 to 25. The above indexes of variation are equal to $(1-R^2) \times 100$ where R^2 is the coefficient of determination.

Table 3

INDEXES OF MARGINAL COST PRICE VARIATION WHEN INVESTMENT OCCURS ONCE EVERY TEN YEARS 1/

CASE	TMC	TLRIC	PWISC	AIC
A	99	15	1	0
B	n.a. 2/	n.a.	n.a.	n.a.
C	83	23	23	23

1/ Larger indexes represent greater variation about a trend line. The trend line was estimated by a least squares regression of the form $MC = a+bt+ct^2$ where MC is the marginal cost price and t is time going from 1 to 25. The above indexes of variation are equal to $(1-R^2) \times 100$ where R^2 is the coefficient of determination.

2/ Not applicable. When no trend is present such as in Case B, the index provides no meaningful results.

Table 4

STANDARDIZED RANGES[1/] OF MARGINAL COST ESTIMATES FOR THE

25 YEAR SIMULATION PERIOD

CASE		TMC	TLRIC	AIC	PWISC
A	1.	14.01	2.00	1.78	1.92
	2.	8.64	1.64	1.77	1.91
	3.	1.82	1.82	1.77	1.80
B	4.	6.47	.03	.34	.44
	5.	3.58	.03	.15	.21
	6.	.07	.07	.01	.12
C	7.	6.51	2.14	.91	2.07
	8.	3.45	1.45	.70	1.38
	9.	.59	.59	.57	.53

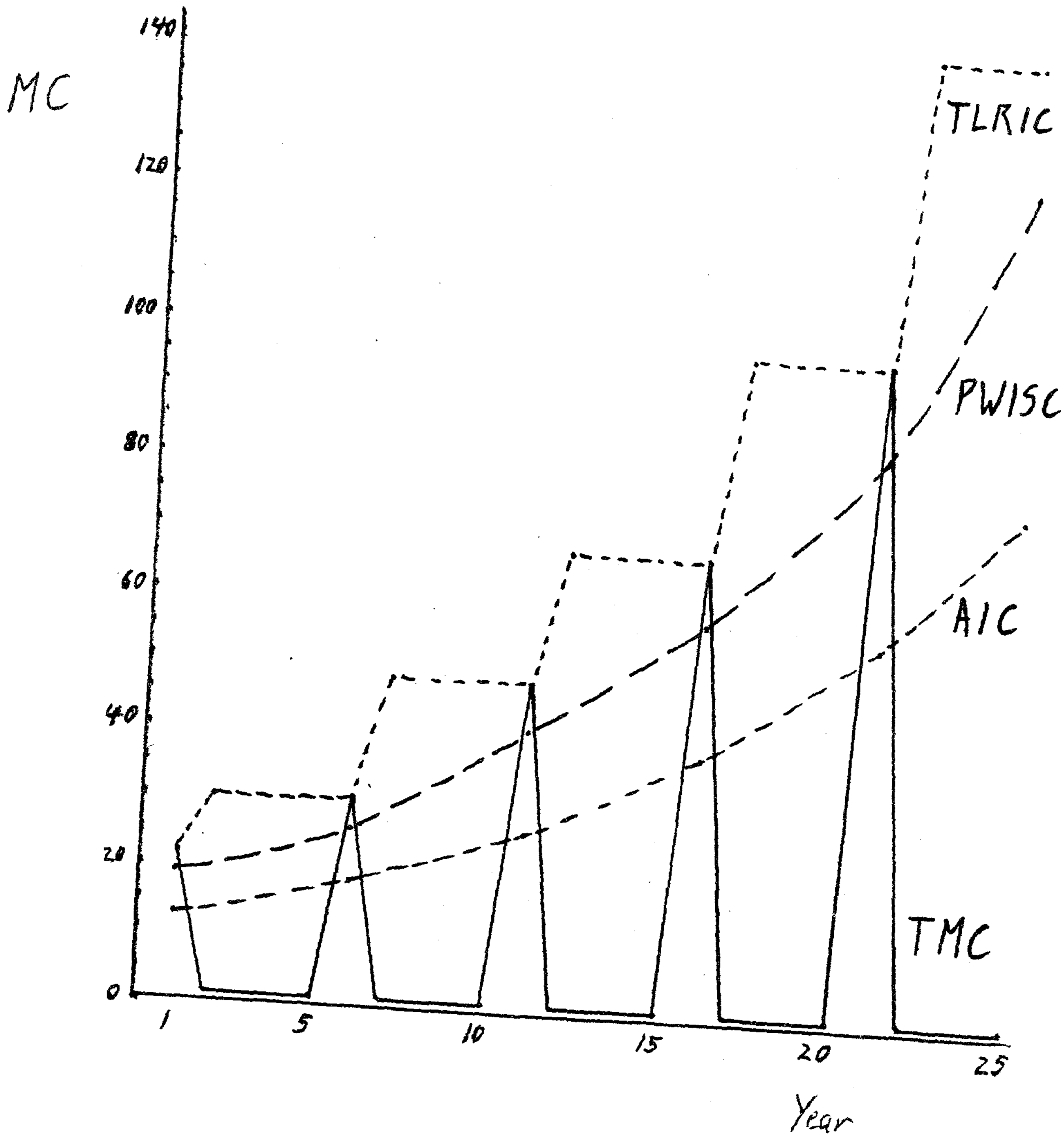
1/ A standardized range is calculated by dividing the difference between the maximum and minimum values by the arithmetic mean of the values for the twenty-five year period.

tions have been made about the size of quantity increments, about discontinuities in costs, and about investment justification being signaled when consumers reveal their willingness to bear the yearly financial burden imposed by a new investment and not the total cost of the investment at that time. Moreover, efficiency may in fact require, to assist long term investment decisions by consumers, the incorporation of capacity costs in price even during periods of excess capacity. From Graphs 1, 2 and 3 it can be seen that TLRIC corresponds exactly to TMC in years where investment justification must be signaled, but that TLRIC is extremely inefficient when judged in light of the need to encourage the use of excess capacity in the short run. PWISC, while also coming close to TMC during years in which investment justification needs to be signaled, does not deviate quite as much from TMC during years in which no investment takes place. AIC on the other hand misses TMC by a wide margin during investment years, but deviates much less from TMC during years in which excess capacity exists.

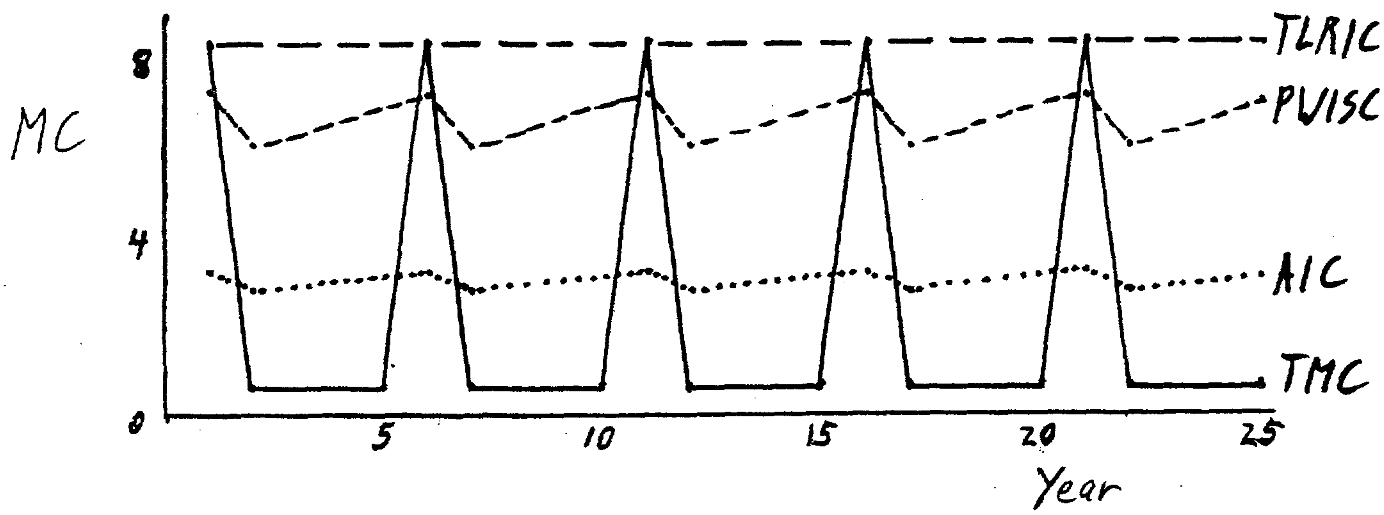
The changing patterns of the deviations from TMC as investment becomes less lumpy can be seen in Graphs 4, 5 and 6 which show investment taking place every five years, and in Graphs 7, 8 and 9 in which investment takes place in each year (the smooth investment stream). As might be expected the marginal cost estimates tend to converge as investment becomes less lumpy, with complete convergence between TMC and TLRIC when investment occurs in each year. Just as it does in the lumpy case, PWISC continues to lag slightly below TLRIC as investment smooths out. AIC tends to underestimate investment signals by a smaller percentage amount as investment smooths out, and in the increasing and constant cost cases actually exceeds the investment signal prices when investment occurs in each year.

Tables 5 and 6 present general summaries of "average" yearly divergences of the three alternative definitions from TMC. As was apparent from the graphs,

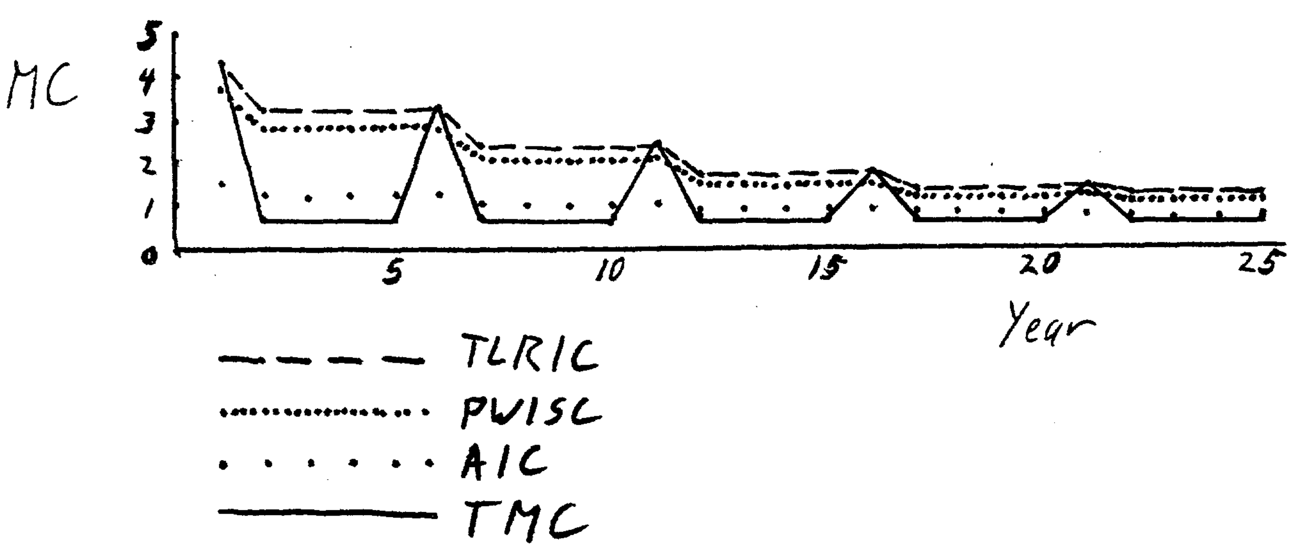
GRAPH 4
CASE A - Investment Every 5 Years



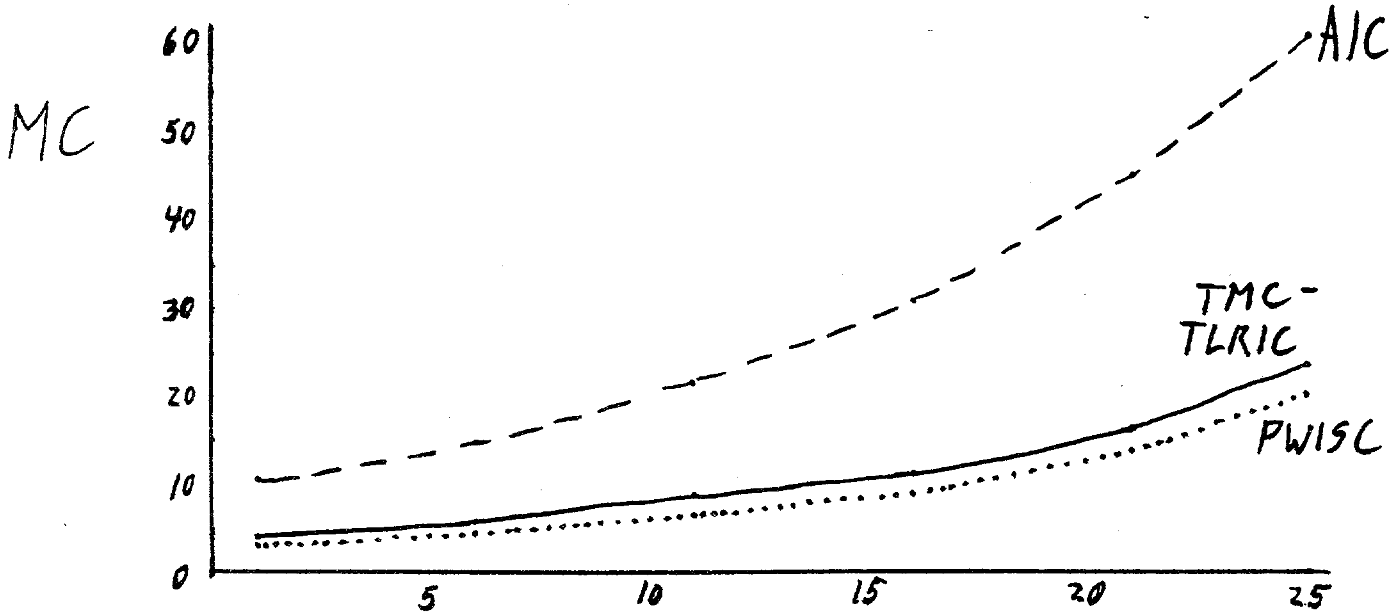
GRAPH 5
CASE B - Investment Every 5 Years



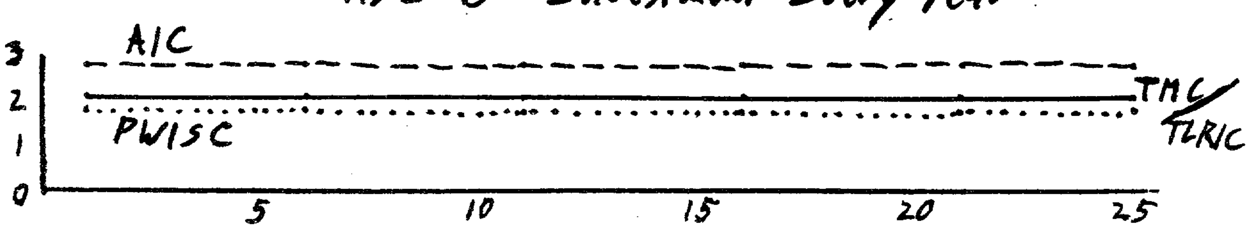
GRAPH 6
CASE C - Investment Every 5 Years



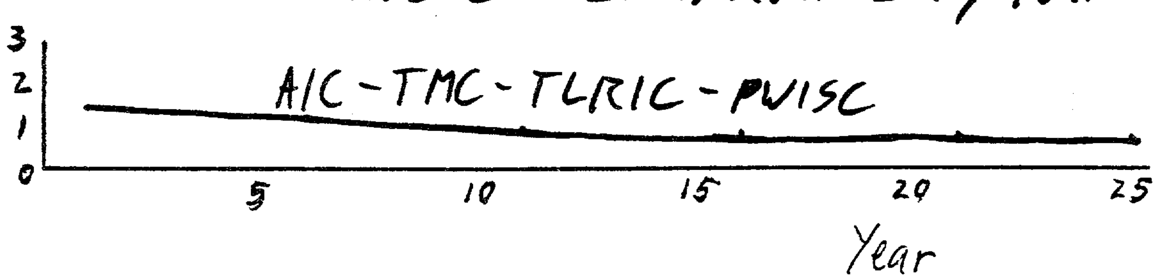
GRAPH 7
CASE A - Investment Every Year



GRAPH 8
CASE B - Investment Every Year



GRAPH 9
CASE C - Investment Every Year



the tables also show that the three alternative definitions tend to converge toward TMC as investment smooths out. Unlike the graphic presentation, however, Tables 5 and 6 better highlight the fact that AIC and TMC generally diverge the least when investment is somewhat lumpy.

The 25 year averages presented in Tables 5 and 6, of course, obscure the fact that AIC misses investment signals, and misses the TMC price in years when excess capacity exists. Furthermore, the averages give deviations in each year an equal weight, whether or not investment takes place in that year. As such, they incorporate the implicit assumption that, in any one year, missing a proper excess capacity allocation price is as large an error as missing an investment signal price. Given this assumption, AIC gives a better "overall" resource allocation price when investment is lumpy, and TMC-TLRIC provide the best resource allocation price when investment is smooth.

It is apparent that subject to the necessary discounting, AIC treats short and long run efficiency as equally valuable. In other words, the rationale for AIC is that in discounting the program benefits (measured in terms of willingness to pay) and discounting program costs, if the present worth of benefits exceeds that of the costs, the proposed investment stream (program) is signalled as justified. The AIC definition, therefore, provides the information needed for cost-benefit analysis. Indeed, the internal rate of return calculation used in the World Bank which for public utilities uses expected revenues as a proxy for benefits, makes use of identical data. Consequently, if prices on average equal AIC, the internal rate of return of the projected investment program is by definition equal to the opportunity cost of capital.

Table 5

AVERAGE ABSOLUTE DIVERGENCE OF ALTERNATIVE MARGINAL COST ESTIMATES FROM TMC [1/]

CASE		TLRIC	AIC	PWISC
A	1.	221.94	52.79	126.27
	2.	61.23	33.25	45.59
	3.	0.00	18.14	1.45
B	4.	15.78	4.10	10.78
	5.	6.28	2.97	4.99
	6.	0.00	.83	.20
C	7.	2.05	.72	1.84
	8.	1.09	.55	2.47
	9.	0.00	.02	.05

1/ The divergences were calculated by summing the absolute differences between the TMC price estimate and the price estimate of each alternative definition and dividing by 25.

Table 6

AVERAGE RATIOS OF ALTERNATIVE MARGINAL COST ESTIMATES TO TMC 1/

CASE		TLRIC / TMC	AIC / TMC	FWISC / TMC
	1.	335.52	61.69	187.49
A	2.	93.61	44.24	67.54
	3.	1.00	2.65	.87
	4.	24.68	4.46	16.70
B	5.	10.45	3.79	8.14
	6.	1.00	1.40	.90
	7.	4.08	1.32	3.63
C	8.	2.64	1.25	2.38
	9.	1.00	.98	.96

1/ The averages presented are calculated by summing the ratios over 25 years and dividing by 25.

In particular instances, of course, when investment is lumpy and when it is felt, for reasons associated with the project, the program, or the country, that a greater value should be placed on signaling the justification of specific lumps of investment, then deviations from TMC during years in which investment takes place might be weighted more heavily, and as a result TLRIC or PWISC could be preferable to the AIC estimates. At the other extreme, if it was decided that investment signals were completely unimportant, and deserved no weight whatsoever, a price equal to short run marginal cost (SMC) would better allocate short run excess capacity than does AIC.

3. Revenue Generation

Table 7 shows the average price of each of the marginal cost definitions over the twenty-five year simulation period. Table 8 shows the total revenue which would be generated over 25 years by each of the definitions for each cost-output stream. Taking either the narrow financial point of view of a water supply utility, or in light of the wider fiscal potential of the utility, it is assumed, for purposes of this exercise, that a higher average price and a higher total of revenues are generally desirable. Revenue surpluses might be dealt with by making grants to the central government, or by further subsidizing connection charges for low income consumers and extending service more rapidly to low income areas as they develop.

From Table 8 it can be seen that in the increasing and constant cost cases for the two lumpy cost streams, TLRIC generates the most revenue followed by PWISC and AIC, with TMC generating the least. For the smooth cost stream, AIC generates the most revenue and PWISC the least when costs are increasing, while TMC-TLRIC generates the least when costs are constant. In the declining cost case revenue

Table 7

ARITHMETIC MEANS[1/] OF MARGINAL COST ESTIMATES

CASE		TMC	TLRIC	AIC	PWISC
	1.	18.05	239.98	45.76	139.34
A	2.	11.22	72.45	35.22	53.79
	3.	10.82	10.82	28.96	9.37
	4.	2.81	18.59	3.45	12.98
B	5.	2.24	8.52	3.15	6.78
	6.	2.08	2.08	2.91	1.88
	7.	1.19	3.24	1.00	2.88
C	8.	1.07	2.16	.99	1.94
	9.	1.00	1.00	.98	.95

1/ The arithmetic means are calculated by dividing the sum of the price estimates for the 25 years by 25.

Table 8

ESTIMATES OF PRESENT WORTH OF REVENUES GENERATED BY EACH MARGINAL COST PRICE OVER THE 25 YEAR SIMULATION PERIOD 1/

CASE		TMC	TLRIC	AIC	PWISC
	1.	487.9	5747.8	1096.2	3327.0
A	2.	315.2	1735.8	844.9	1287.7
	3.	263.4	263.4	695.8	228.7
	4.	126.0	767.8	142.3	535.4
B	5.	98.5	351.8	129.8	279.7
	6.	85.8	85.8	120.0	77.5
	7.	81.1	221.0	68.4	196.1
C	8.	72.6	147.0	67.7	132.4
	9.	65.0	65.0	66.8	64.7

1/ Present worth of the streams of revenues generated over the 25 year period.

generated is roughly the same for all definitions for the smooth investment stream, while TLRIC and PWISC generate significantly greater amounts when costs are lumpy.

4. The Price of Elasticity of Demand

As noted in the previous sections, the simulations which we have undertaken in this paper are based on the assumption that the price elasticity of demand for water is zero. This assumption is made in order to permit an examination of the alternative marginal cost definitions in the extreme case when investments occur at precisely the same time intervals and in similar magnitudes, irrespective of what price is actually being charged. As such, this allows differences among the marginal cost estimates, particularly with regard to volatility, to be highlighted.

It is clear, however, that if we relax the zero price elasticity assumption, the volatility of all the estimates tends to decline. For example, in the typical case in which there is capital indivisibility and unit investment costs are rising, if demand were relatively price elastic, pricing according to TMC would result in consumption reaching capacity relatively quickly when price was set equal to short run marginal cost, and then remaining fixed as price rises slowly through time (in order to clear the market) until it equals the sum of short run marginal cost and marginal capacity cost. Thus, price would rise slowly between investments, and each investment would tend to be pushed further into the future. Likewise, if price were equated to TLRIC under conditions in which demand was relatively price elastic, investment would again be pushed further into the future and the through time volatility of price would be reduced.

An assumption of relatively inelastic demand does, however, have relevance for the case of water supply (and electric power).[1/] There is some evidence that, at currently experienced price ranges, demand for water supply tends to be fairly inelastic. And an assumption of a price elasticity of demand, say, of -0.2[2/] does not materially affect the general conclusion which have been drawn from the simulation exercises described in this paper. Furthermore, in practice, even where demand is as inelastic as this, there are important efficiency implications of alternative pricing policies. For example, a 50 percent increase in water charges - which would frequently be the minimum necessary to raise price to the level of AIC - would, in these circumstances, reduce consumption by 10 percent, and allow many cities in developing countries to either achieve one or two years' postponement in their capital investment plans, or to expand service more rapidly to those currently without potable water supply or with only intermittent supply.

1/ Clearly as noted earlier, if there were zero elasticity of demand, the analysis outlined in this paper would be irrelevant, as there would be no efficiency grounds for choosing marginal cost pricing over any other pricing rule.

2/ The estimate of -0.2 has been found to be applicable for domestic water use in the USA. See: Howe, C.W. and F.P. Linaweaver, Jr., 1967, "The Impact of Price of Residential Water and its Relation to System Design and Price Structure," Water Resources Research, Vol.3, No.1.

IV. Conclusion

One of the objectives of this exercise was to determine whether or not one unambiguous definition of marginal cost can be derived which would be appropriate for public utility pricing purposes in all circumstances. The results of our analysis suggest that it cannot. If we reject the "textbook" marginal cost approach on practical grounds, the choice, among the methods selected for analysis, lies between the TLRIC/PWISC methods (which are somewhat similar) on the one hand and AIC on the other.

The general conclusion that stems from the simulation results suggests that where investment streams are fairly continuous (little "lumpiness" or excess capacity) TLRIC/PWISC are likely to be acceptable methods to use, since price fluctuations are minimal, and the price charged corresponds as closely as practicable to our estimate of TMC. It is when capital indivisibility enters the picture that AIC can become more appropriate, for then compromises must be reached between the need to avoid price fluctuation, the need to signal the justification of investment, and the need to make the best use of existing capacity. In retrospect, therefore, it is not surprising that while PWISC/TLRIC have been used in the analysis of tariff structures for large electric power systems (where capital indivisibility has been a relatively small problem or has been assumed away), AIC has been developed, quite independently, to deal with lumpy investment streams, such as those frequently encountered in water supply.

Of course, some water supply investment programs show little capital indivisibility while many power development programs, particularly in poorer countries, show great indivisibility. There are therefore circumstances in which AIC can be more appropriate for electric power, and circumstances in which TLRIC/PWISC should be applied in the water supply field. What is clear is that the greater the degree of capital divisibility, the closer we can get to theoretically optimal pricing: TLRIC/PWISC are therefore likely to be associated with "better" pricing policies than AIC, which has been devised to apply in lumpy investment conditions, and where exogenous constraints such as the political and financial unacceptability of relatively large price fluctuations do not allow optimality in the traditional sense to be achieved.

There are of course an infinite number of adaptations that may be made to the definitions of marginal cost which we have analyzed, and it is easy to conceive of situations in which combinations of these methods could be employed. For example, if a situation exists where there is considerable excess capacity, sufficient for say the next ten years, it might be appropriate to estimate the TLRIC price that should prevail ten years hence, discount this to its present worth and set current price at that level, and then over the intervening period gradually adjust price so that it reflects the TLRIC estimate of the long term trend in incremental costs. Such cases are not uncommon. Recent analysis carried out in the World Bank have shown that at least ten years excess production capacity exists for water supply in Bogota and for power in Ethiopia.

A simple arithmetic smoothing of marginal cost price estimates has also been suggested by Turvey who recently averaged through time an estimate of marginal cost which corresponds closely to our TMC definition.[1/] We also undertook several price smoothing simulations similar to Turvey's and found that while the characteristics of an "averaged" TMC were similar to AIC, if compared on a year by year

1/ Turvey, Ralph "Analyzing the Marginal Cost of Water Supply," Land Economics, Vol. 52, No. 2, May 1976, pp.158-168. The general method is described in Turvey, Ralph and Dennis Anderson, Electricity Economics: Essays and Case Studies, op.cit., Chapter 17.

basis the "averaged" TMC tended to be slightly more volatile.[1/] Also, unlike AIC, the "averaged" TMC does not provide a signal that an investment program is justified, and in the simulations showed a lower revenue generating capacity.[2/]

There are therefore a number of ways in which marginal cost can be defined for pricing purposes when there is significant capital indivisibility. Compromises are clearly required, the type of compromise that is suitable depending in part upon the degree of capital indivisibility, the stage of the project and program cycle at which the pricing decision is being made, the elasticities of demand for water, and, not least, the prices which currently prevail. The need for the judgement implied by these complications suggests that particularly where capital indivisibility is present, it is not possible to establish a set of precise rules that can be followed mechanically by anyone who happens to be interested in applying marginal cost pricing in the utility field. The combination of art and science necessary for tariff making clearly requires the involvement of a specialist, even if his terms of reference are restricted to the efficiency aspects of pricing policy.

1/ The "Averaged" Textbook Marginal Cost which we simulated is as follows:

$$ATMC_t = r \sum_{\hat{t}=1}^{T} \frac{TMC_{t+\hat{t}-1}}{(1+i)^{\hat{t}-1}}$$

where: t = The year for which ATMC is being calculated
r = The same as r in TMC
i = The same as i in AIC

Essentially this involves calculating a price which, when assigned to each of T years, has the same present worth per year for T years as the present worth of TMC for T years.

2/ For the results of simulations of ATMC in which T=20, r=0.1175 and i=0.10, see Appendix IV.

OPERATING COST AND OUTPUT DATA USED IN THE SIMULATIONS

Since the results of the simulations are only intended to be used for comparative purposes, the units in which the operating cost and output data are presented in the following table are not defined.

Table I-1

Operating Cost and Output Data

	Operating Costs			Output		
Year	2% annual growth	5 % annual growth	10 % annual growth	2 % annual growth	5 % annual growth	10 % annual growth
1	2.00	2.00	2.00	3.00	3.00	3.00
2	2.04	2.10	2.20	3.06	3.15	3.30
3	2.08	2.20	2.42	3.12	3.31	3.63
4	2.12	2.32	2.66	3.18	3.47	3.99
5	2.16	2.43	2.93	3.25	3.65	4.39
6	2.21	2.55	3.22	3.31	3.83	4.83
7	2.25	2.68	3.54	3.38	4.02	5.31
8	2.30	2.81	3.90	3.45	4.22	5.85
9	2.34	2.95	4.29	3.51	4.43	6.43
10	2.39	3.10	4.72	3.59	4.65	7.07
11	2.44	3.26	5.19	3.66	4.89	7.78
12	2.49	3.42	5.71	3.73	5.13	8.56
13	2.54	3.59	6.28	3.80	5.39	9.42
14	2.59	3.77	6.90	3.88	5.66	10.36
15	2.64	3.96	7.59	3.96	5.94	11.39
16	2.69	4.16	8.35	4.04	6.24	12.53
17	2.75	4.37	9.19	4.12	6.55	13.78
18	2.80	4.58	10.11	4.20	6.88	15.16
19	2.86	4.81	11.12	4.28	7.22	16.68
20	2.91	5.05	12.23	4.37	7.58	18.35
21	2.97	5.31	13.45	4.46	7.96	20.18
22	3.03	5.57	14.80	4.55	8.36	22.20
23	3.09	5.85	16.28	4.64	8.78	24.42
24	3.15	6.14	17.91	4.73	9.21	26.86
25	3.22	6.45	19.70	4.83	9.68	29.55
26	3.28	6.77	21.67	4.92	10.16	32.50
27	3.35	7.11	23.84	5.02	10.67	35.75
28	3.41	7.47	26.22	5.12	11.20	39.33
29	3.48	7.84	28.84	5.22	11.76	43.26
30	3.55	8.23	31.73	5.33	12.35	47.59
31	3.62	8.64	34.90	5.43	12.97	52.35
32	3.70	9.08	38.39	5.54	13.61	57.58
33	3.77	9.53	42.23	5.65	14.29	63.34
34	3.84	10.01	46.45	5.77	15.01	69.68
35	3.92	10.51	51.10	5.88	15.76	76.64
36	4.00	11.03	56.20	6.00	16.55	84.31
37	4.08	11.58	61.83	6.12	17.38	92.74
38	4.16	12.16	68.01	6.24	18.24	102.00
39	4.24	12.77	74.81	6.37	19.16	112.20
40	4.33	13.41	82.29	6.49	20.11	123.40
41	4.42	14.08	90.52	6.62	21.12	135.80
42	4.50	14.78	99.57	6.76	22.18	149.40
43	4.59	15.52	109.50	6.89	23.28	164.30
44	4.69	16.30	120.50	7.03	24.45	180.70
45	4.78	17.11	132.50	7.17	25.67	198.80
46	4.88	17.97	145.80	7.31	26.96	218.70
47	4.97	18.87	160.40	7.46	28.30	240.50
48	5.07	19.81	176.40	7.61	29.72	264.60
49	5.17	20.80	194.00	7.76	31.20	291.00
50	5.28	21.84	213.40	7.92	32.76	320.20

INVESTMENT COST DATA USED IN THE SIMULATIONS

Since the results of the simulations are only intended to be used for comparative purposes, the units or currency in which the investment cost data are presented in the following tables are not defined.

Table II-1

Investment Cost Data

CASE A - Increasing Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	31.880	12.210	2.000
2	0.000	0.000	2.200
3	0.000	0.000	2.420
4	0.000	0.000	2.660
5	0.000	0.000	2.930
6	0.000	19.670	3.220
7	0.000	0.000	3.540
8	0.000	0.000	3.900
9	0.000	0.000	4.290
10	0.000	0.000	4.720
11	82.670	31.670	5.190
12	0.000	0.000	5.710
13	0.000	0.000	6.280
14	0.000	0.000	6.900
15	0.000	0.000	7.590
16	0.000	51.000	8.350
17	0.000	0.000	9.190
18	0.000	0.000	10.110
19	0.000	0.000	11.120
20	0.000	0.000	12.230
21	214.400	82.140	13.450
22	0.000	0.000	14.800
23	0.000	0.000	16.280
24	0.000	0.000	17.910
25	0.000	0.000	19.700
26	0.000	132.300	21.670
27	0.000	0.000	23.840
28	0.000	0.000	26.220
29	0.000	0.000	28.840
30	0.000	0.000	31.730
31	556.200	213.000	34.900
32	0.000	0.000	38.390
33	0.000	0.000	42.230
34	0.000	0.000	46.450
35	0.000	0.000	51.100
36	0.000	343.100	56.200
37	0.000	0.000	61.830
38	0.000	0.000	68.010
39	0.000	0.000	74.810
40	0.000	0.000	82.290
41	1442.000	552.500	90.520
42	0.000	0.000	99.570
43	0.000	0.000	109.500
44	0.000	0.000	120.500
45	0.000	0.000	132.500
46	0.000	890.000	145.800
47	0.000	0.000	160.400
48	0.000	0.000	176.400
49	0.000	0.000	194.000
50	0.000	0.000	213.400

Table II-2

Investment Cost Data

CASE B - Constant Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	25.140	11.050	2.000
2	0.000	0.000	2.100
3	0.000	0.000	2.200
4	0.000	0.000	2.320
5	0.000	0.000	2.430
6	0.000	14.090	2.550
7	0.000	0.000	2.680
8	0.000	0.000	2.810
9	0.000	0.000	2.950
10	0.000	0.000	3.100
11	40.970	18.000	3.260
12	0.000	0.000	3.420
13	0.000	0.000	3.590
14	0.000	0.000	3.770
15	0.000	0.000	3.960
16	0.000	22.970	4.160
17	0.000	0.000	4.370
18	0.000	0.000	4.580
19	0.000	0.000	4.810
20	0.000	0.000	5.050
21	66.740	29.320	5.310
22	0.000	0.000	5.570
23	0.000	0.000	5.850
24	0.000	0.000	6.140
25	0.000	0.000	6.450
26	0.000	37.420	6.770
27	0.000	0.000	7.110
28	0.000	0.000	7.470
29	0.000	0.000	7.840
30	0.000	0.000	8.230
31	108.700	47.770	8.640
32	0.000	0.000	9.080
33	0.000	0.000	9.530
34	0.000	0.000	10.010
35	0.000	0.000	10.510
36	0.000	60.950	11.030
37	0.000	0.000	11.580
38	0.000	0.000	12.160
39	0.000	0.000	12.770
40	0.000	0.000	13.410
41	177.000	77.790	14.080
42	0.000	0.000	14.780
43	0.000	0.000	15.520
44	0.000	0.000	16.300
45	0.000	0.000	17.110
46	0.000	99.290	17.970
47	0.000	0.000	18.870
48	0.000	0.000	19.810
49	0.000	0.000	20.800
50	0.000	0.000	21.840

Table II-3

Investment Cost Data

CASE C - Declining Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	21.890	10.400	2.000
2	0.000	0.000	2.040
3	0.000	0.000	2.080
4	0.000	0.000	2.120
5	0.000	0.000	2.160
6	0.000	11.490	2.210
7	0.000	0.000	2.250
8	0.000	0.000	2.300
9	0.000	0.000	2.340
10	0.000	0.000	2.390
11	26.710	12.700	2.440
12	0.000	0.000	2.490
13	0.000	0.000	2.540
14	0.000	0.000	2.590
15	0.000	0.000	2.640
16	0.000	14.010	2.690
17	0.000	0.000	2.750
18	0.000	0.000	2.800
19	0.000	0.000	2.860
20	0.000	0.000	2.910
21	32.530	15.460	2.970
22	0.000	0.000	3.030
23	0.000	0.000	3.090
24	0.000	0.000	3.150
25	0.000	0.000	3.220
26	0.000	17.070	3.280
27	0.000	0.000	3.350
28	0.000	0.000	3.410
29	0.000	0.000	3.480
30	0.000	0.000	3.550
31	39.660	18.850	3.620
32	0.000	0.000	3.700
33	0.000	0.000	3.770
34	0.000	0.000	3.840
35	0.000	0.000	3.920
36	0.000	20.810	4.000
37	0.000	0.000	4.080
38	0.000	0.000	4.160
39	0.000	0.000	4.240
40	0.000	0.000	4.330
41	48.350	22.980	4.420
42	0.000	0.000	4.500
43	0.000	0.000	4.590
44	0.000	0.000	4.690
45	0.000	0.000	4.780
46	0.000	25.370	4.880
47	0.000	0.000	4.970
48	0.000	0.000	5.070
49	0.000	0.000	5.170
50	0.000	0.000	5.280

ESTIMATES OF MARGINAL COST RESULTING FROM THE SIMULATIONS

The following tables present estimates of the marginal cost prices that would prevail in each year of a 25 year period. As in the previous annexes, the estimates are only intended to be used for comparative purposes; the units and currency in which the prices are presented are not defined.

Table III-1

TMC Price Estimates

CASE A - Increasing Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	57.042	22.259	4.203
2	0.667	0.667	4.557
3	0.667	0.667	4.946
4	0.571	0.571	4.603
5	0.833	0.833	6.015
6	0.571	30.386	5.452
7	0.714	0.714	6.080
8	0.667	0.667	7.563
9	0.625	0.625	6.315
10	0.714	0.714	7.868
11	126.019	48.717	8.581
12	0.714	0.714	9.369
13	0.625	0.625	8.954
14	0.625	0.625	9.776
15	0.625	0.625	10.691
16	0.750	68.389	11.824
17	0.625	0.625	12.813
18	0.750	0.750	14.158
19	0.556	0.556	13.665
20	0.667	0.667	15.085
21	253.420	97.500	16.523
22	0.667	0.667	18.114
23	0.667	0.667	19.859
24	0.700	0.700	19.702
25	0.667	0.667	23.891

Table III-2

TLRIC Price Estimates

CASE A - Increasing Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	57.042	22.258	4.203
2	125.971	30.481	4.557
3	125.971	30.481	4.946
4	125.876	30.386	4.603
5	126.138	30.648	6.015
6	125.876	30.386	5.452
7	126.019	48.717	6.080
8	125.971	48.670	7.563
9	125.930	48.628	6.315
10	126.019	48.717	7.868
11	126.019	48.717	8.581
12	253.467	68.353	9.369
13	253.378	68.264	8.954
14	253.378	68.264	9.776
15	253.378	68.264	10.691
16	253.503	68.389	11.824
17	253.378	97.459	12.813
18	253.503	97.584	14.158
19	253.309	97.389	13.665
20	253.420	97.500	15.085
21	253.420	97.500	16.523
22	537.143	141.036	18.114
23	537.143	141.036	19.859
24	537.177	141.070	19.702
25	537.143	141.036	23.891

Table III-3

AIC Price Estimates

CASE A- Increasing Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	16.435	12.747	10.560
2	17.658	13.691	11.335
3	18.950	14.676	12.149
4	20.274	15.691	12.971
5	22.098	17.091	14.121
6	23.526	18.181	15.010
7	25.512	19.705	16.261
8	27.592	21.297	17.565
9	29.217	22.542	18.584
10	32.020	24.691	20.345
11	34.386	26.503	21.827
12	36.837	28.376	23.361
13	39.346	30.297	24.933
14	42.649	32.829	27.006
15	46.124	35.493	29.190
16	49.779	38.294	31.486
17	53.571	41.197	33.863
18	57.518	44.222	36.341
19	61.569	47.322	38.879
20	66.757	51.301	42.140
21	72.230	55.494	45.575
22	77.963	59.891	49.180
23	83.936	64.467	52.928
24	90.135	69.218	56.819
25	97.896	75.163	61.688

Table III-4

PWISC Price Estimates

CASE A - Increasing Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	48.970	19.167	3.697
2	53.787	21.022	4.000
3	59.101	23.058	4.333
4	55.666	21.683	4.026
5	71.538	27.927	5.273
6	67.236	26.117	4.753
7	74.044	28.806	5.312
8	94.775	36.718	6.576
9	78.263	30.367	5.500
10	98.316	38.104	6.844
11	108.078	41.844	7.455
12	118.801	45.953	8.130
13	114.283	44.167	7.761
14	125.649	48.521	8.466
15	138.149	53.310	9.250
16	152.029	58.704	10.239
17	167.031	64.378	11.068
18	183.797	70.878	12.239
19	179.533	69.125	11.788
20	197.544	76.094	13.020
21	217.231	83.636	14.252
22	238.931	91.941	15.616
23	262.758	101.069	17.111
24	260.169	100.098	16.982
25	317.800	122.154	20.566

Table III-5

TMC Price Estimates

CASE B - Constant Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	18.449	8.483	2.081
2	0.625	0.625	2.018
3	0.750	0.750	2.209
4	0.611	0.611	1.979
5	0.667	0.667	2.099
6	0.684	8.552	2.108
7	0.650	0.650	2.072
8	0.667	0.667	2.086
9	0.682	0.682	2.105
10	0.667	0.667	2.037
11	18.779	8.624	2.108
12	0.654	0.654	2.049
13	0.667	0.667	2.077
14	0.679	0.679	2.107
15	0.667	0.667	2.067
16	0.677	8.539	2.101
17	0.636	0.636	2.041
18	0.676	0.676	2.106
19	0.667	0.667	2.084
20	0.684	0.684	2.094
21	18.353	8.427	2.058
22	0.667	0.667	2.074
23	0.674	0.674	2.118
24	0.660	0.660	2.046
25	0.667	0.667	2.092

Table III-6

TLRIC Price Estimates

CASE B - Constant Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	18.449	8.483	2.081
2	18.737	8.493	2.018
3	18.862	8.618	2.209
4	18.723	8.479	1.979
5	18.779	8.535	2.099
6	18.796	8.552	2.108
7	18.762	8.608	2.072
8	18.779	8.624	2.086
9	18.794	8.639	2.105
10	18.779	8.624	2.037
11	18.779	8.624	2.108
12	18.357	8.516	2.049
13	18.369	8.528	2.077
14	18.381	8.540	2.107
15	18.369	8.528	2.067
16	18.380	8.539	2.101
17	18.339	8.413	2.041
18	18.379	8.454	2.106
19	18.369	8.444	2.084
20	18.387	8.461	2.094
21	18.353	8.427	2.058
22	18.687	8.451	2.074
23	18.695	8.459	2.118
24	18.680	8.444	2.046
25	18.687	8.451	2.092

Table III-7

AIC Price Estimates

CASE B - Constant Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	4.112	3.379	2.908
2	2.934	2.919	2.908
3	3.050	3.035	2.917
4	3.146	3.129	2.900
5	3.281	3.264	2.915
6	3.402	3.383	2.912
7	3.528	2.919	2.908
8	3.664	3.027	2.908
9	3.805	3.138	2.907
10	3.949	3.252	2.904
11	4.117	3.384	2.912
12	2.932	2.918	2.907
13	3.045	3.030	2.912
14	3.159	3.143	2.913
15	3.274	3.257	2.909
16	3.401	3.384	2.912
17	3.528	2.920	2.909
18	3.670	3.033	2.914
19	3.809	3.141	2.911
20	3.957	3.258	2.910
21	4.113	3.380	2.909
22	2.936	2.923	2.912
23	3.046	3.031	2.913
24	3.153	3.138	2.907
25	3.278	3.262	2.913

Table III-8

PWISC Price Estimates

CASE B - Constant Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	15.903	7.364	1.879
2	10.497	6.093	1.818
3	11.610	6.765	2.000
4	11.229	6.492	1.783
5	12.347	7.136	1.894
6	12.856	7.426	1.904
7	13.370	6.238	1.868
8	13.992	6.521	1.883
9	14.673	6.829	1.901
10	14.775	6.865	1.841
11	16.186	7.485	1.902
12	10.550	6.139	1.850
13	11.150	6.477	1.875
14	11.798	6.842	1.903
15	12.083	6.994	1.867
16	12.830	7.413	1.897
17	13.194	6.153	1.840
18	14.084	6.566	1.901
19	14.595	6.786	1.881
20	15.199	7.061	1.892
21	15.818	7.314	1.857
22	10.645	6.199	1.872
23	11.395	6.618	1.911
24	11.449	6.641	1.847
25	12.287	7.109	1.888

Table III-9

TMC Price Estimates

CASE C - Declining Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	8.408	4.345	1.374
2	0.667	0.667	1.323
3	0.667	0.667	1.280
4	0.675	0.675	1.237
5	0.659	0.659	1.180
6	0.667	3.206	1.155
7	0.667	0.667	1.109
8	0.672	0.672	1.093
9	0.672	0.672	1.060
10	0.662	0.662	1.019
11	4.300	2.394	0.999
12	0.663	0.663	0.970
13	0.660	0.660	0.946
14	0.670	0.670	0.937
15	0.667	0.667	0.912
16	0.672	1.861	0.900
17	0.667	0.667	0.878
18	0.664	0.664	0.860
19	0.665	0.665	0.846
20	0.667	0.667	0.835
21	2.377	1.480	0.824
22	0.667	0.667	0.811
23	0.668	0.668	0.802
24	0.665	0.665	0.790
25	0.668	0.668	0.784

Table III-10

TLRIC Price Estimates

CASE C - Declining Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	8.408	4.345	1.374
2	4.300	3.206	1.323
3	4.300	3.206	1.280
4	4.308	3.215	1.237
5	4.292	3.199	1.180
6	4.300	3.206	1.155
7	4.300	2.394	1.109
8	4.306	2.400	1.093
9	4.305	2.399	1.060
10	4.295	2.389	1.019
11	4.300	2.394	0.999
12	2.371	1.852	0.970
13	2.368	1.849	0.946
14	2.379	1.859	0.937
15	2.375	1.856	0.912
16	2.381	1.861	0.900
17	2.375	1.479	0.878
18	2.373	1.477	0.860
19	2.373	1.477	0.846
20	2.375	1.479	0.835
21	2.377	1.480	0.824
22	1.471	1.224	0.811
23	1.473	1.225	0.802
24	1.470	1.223	0.790
25	1.472	1.225	0.784

Table III-11

AIC Price Estimates

CASE C - Declining Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	1.676	1.475	1.339
2	1.141	1.221	1.290
3	1.141	1.221	1.244
4	1.141	1.221	1.202
5	1.140	1.220	1.163
6	1.141	1.221	1.127
7	1.141	1.047	1.093
8	1.141	1.047	1.063
9	1.141	1.046	1.033
10	1.140	1.046	1.006
11	1.141	1.046	0.982
12	0.889	0.927	0.959
13	0.890	0.927	0.938
14	0.890	0.928	0.919
15	0.890	0.927	0.900
16	0.890	0.927	0.883
17	0.889	0.845	0.867
18	0.889	0.845	0.852
19	0.890	0.845	0.839
20	0.890	0.845	0.827
21	0.890	0.845	0.815
22	0.771	0.789	0.804
23	0.771	0.789	0.794
24	0.771	0.789	0.785
25	0.771	0.789	0.776

Table III-12

PWISC Price Estimates

CASE C - Declining Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	7.300	3.818	1.273
2	3.787	2.829	1.229
3	3.813	2.847	1.192
4	3.790	2.833	1.157
5	3.774	2.817	1.105
6	3.808	2.843	1.085
7	3.738	2.127	1.045
8	3.818	2.168	1.033
9	3.807	2.163	1.004
10	3.771	2.140	0.968
11	3.780	2.147	0.951
12	2.121	1.674	0.926
13	2.127	1.678	0.905
14	2.143	1.692	0.898
15	2.131	1.682	0.877
16	2.141	1.691	0.868
17	2.130	1.362	0.848
18	2.126	1.359	0.832
19	2.128	1.360	0.820
20	2.136	1.365	0.811
21	2.132	1.364	0.802
22	1.355	1.144	0.791
23	1.357	1.146	0.783
24	1.353	1.142	0.772
25	1.358	1.146	0.767

75

SIMULATION RESULTS DERIVED FROM AVERAGING THE TEXTBOOK MARGINAL COST ESTIMATES

The following tables present estimates of the "Average Textbook Marginal Cost" (ATMC) price that would prevail in each year of a 25 year period. As in the previous annexes, the estimates are only intended to be used for comparative purposes; the units and currency in which the prices are presented are not defined.

Table IV-1

ATMC Price Estimates

CASE A - Increasing Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	11.8510	8.6590	6.9878
2	10.7598	8.6125	7.4813
3	11.7691	9.4071	8.0104
4	12.8793	10.2810	8.5771
5	14.1123	11.2543	9.2381
6	15.4373	12.2935	9.8724
7	16.9262	12.4163	10.6328
8	18.5454	13.5846	11.4339
9	20.3338	14.8769	12.1868
10	22.3048	16.3022	13.1604
11	24.4636	17.8608	14.1522
12	21.4854	17.5236	15.1598
13	23.5611	19.2031	16.2328
14	25.8540	21.0602	17.4663
15	28.3786	23.1055	18.8594
16	31.1547	25.3542	20.2899
17	34.1937	25.1639	21.8091
18	37.5513	27.6185	23.4510
19	41.2290	30.3030	25.1127
20	45.2997	33.2811	27.1867
21	49.7634	36.5429	29.3180
22	44.0599	36.0641	31.5165
23	48.3996	39.6042	33.9712
24	53.1737	43.4987	36.4967
25	58.4200	47.7776	39.4376

77

Table IV-2

ATMC Price Estimates

CASE B- Constant Unit Investment Costs

	Frequency of Investment		
Year	10 Years	5 Years	Every Year
1	3.3121	2.5522	2.0813
2	1.7961	1.9579	2.0809
3	1.9139	2.0919	2.0881
4	2.0289	2.2247	2.0783
5	2.1716	2.3869	2.0850
6	2.3220	2.5589	2.0834
7	2.4855	1.9575	2.0803
8	2.6695	2.0888	2.0816
9	2.8696	2.2308	2.0809
10	3.0880	2.3853	2.0778
11	3.3300	2.5570	2.0824
12	1.7832	1.9497	2.0799
13	1.8962	2.0794	2.0835
14	2.0191	2.2206	2.0840
15	2.1529	2.3745	2.0812
16	2.3013	2.5451	2.0826
17	2.4635	1.9439	2.0802
18	2.6469	2.0754	2.0851
19	2.8437	2.2151	2.0822
20	3.0615	2.3700	2.0822
21	3.2989	2.5382	2.0806
22	1.7933	1.9494	2.0830
23	1.9060	2.0777	2.0843
24	2.0290	2.2179	2.0801
25	2.1660	2.3737	2.0840

Table IV-3

ATMC Price Estimates

CASE C - Declining Unit Investment Costs

Year	Frequency of Investment: 10 Years	5 Years	Every Year
1	1.6438	1.3301	1.1327
2	.8618	.9784	1.0989
3	.8812	1.0096	1.0675
4	.9026	1.0438	1.0379
5	.9252	1.0805	1.0101
6	.9520	1.1228	.9862
7	.9805	.8798	.9626
8	1.0117	.9010	.9419
9	1.0456	.9238	.9210
10	1.0829	.9488	.9017
11	1.1250	.9776	.8851
12	.7579	.8124	.8692
13	.7675	.8273	.8549
14	.7783	.8442	.8420
15	.7891	.8615	.8288
16	.8012	.8809	.8171
17	.8141	.7666	.8056
18	.8288	.7765	.7955
19	.8453	.7878	.7864
20	.8633	.8001	.7780
21	.8829	.8133	.7699
22	.7101	.7355	.7623
23	.7143	.7423	.7554
24	.7190	.7498	.7489
25	.7244	.7582	.7431