

CALCULATING DEVELOPER CHARGES FOR URBAN INFRASTRUCTURE: A FEASIBLE METHOD FOR APPLYING MARGINAL COST PRICING

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ABSTRACT

This paper considers the application of marginal cost pricing to the calculation of developer charges, also termed exactions or impact fees, in the contemporary urban environment. We derive an "ideal" measure of long-run marginal capacity cost (MCC) of urban infrastructure expansion. Given practical difficulties in estimating MCC, we develop an alternative Adjusted Amortization Method (AAM) with less onerous data requirements. Using a simulation model we compare the magnitudes of developer charges derived from the ideal MCC measure, our AAM method and three other common approaches to the measurement of MCC. Our results show that an adjusted version of the AAM formula performs very well.

INTRODUCTION

In common with other realms of economic endeavor, marginal cost pricing is socially optimal in guiding both the *use* of existing local public services as well as *investment* in these services (Baumol and Bradford [2]). But urban infrastructure, such as water supply, sewerage and drainage, has a number of idiosyncratic features, like lumpiness, uncertainty over demand, and inherited systems, which make the determination of marginal cost in the real world extremely difficult. Turvey [15] argued that in these circumstances marginal costs center on "central system costs" that can be thought of as the "headworks" and major capital works of an infrastructure service network that are characterized by longevity, lumpiness and excess capacity.

Each infrastructure service provider is envisaged as having a schedule of investment plans into the future that optimizes production and investment timing. Put differently, the schedule minimizes the expected present worth of all avoidable costs and no change in the way planned output is produced will lower the present worth of these future costs. If we postulate that demand for the service unexpectedly, but permanently, rises (or falls) by a given amount, then output must also adjust to accommodate this permanent increment. This means that planned future investments will have to be rescheduled. Perhaps a rescheduling of the whole program will be necessary, but at a minimum, the timing of some future expansions of capacity will have to be brought forward. This implies that there will be a new present worth of the stream of future costs that now takes the permanent increment into account. Turvey [13] defined marginal cost as the difference between these two cost streams.

If we accept the convention of excluding expected running costs from developer charges, then we can define an ideal developer charge for headworks and major works of some infrastructural service by applying the Turvey [15] concept of marginal cost. An ideal charge would equal the MCC of the permanent output increment required by the development, measured as follows: The present worth of the least-cost investment expenditure stream *with* the permanent output increment that a development will occasion *less* the present worth of the least-cost investment expenditure stream *without* the increment due to development.

PRAGMATIC CONSIDERATIONS

Notwithstanding the theoretical rectitude in using marginal cost pricing in the provision of public services, governments and other real-world public infrastructure service providers have been extremely reluctant to employ these pricing techniques (Littlechild [5]; Rees [10]). For example, the American Water Works Association [1] has argued that the development of marginal cost pricing is “complex and costly” and “a controversial approach not commonly used in the water industry”. Given the extensive amount of detail on forward expenditure estimates based on hypothetical demand and supply scenarios, there is a strong possibility that infrastructure service providers will also find the data demands of the “ideal” method of calculating marginal capacity costs for developer charges (sometimes also known as exactions or impact fees) prohibitive. This raises important theoretical questions: Do alternative “second-best” measures exist that reduce data requirements but nevertheless retain these general principles? If so, to what extent would the costs measured by the simpler

methods depart from the ideal and how would they vary under differing conditions? We now turn our attention to these questions.

ALTERNATIVE MARGINAL COST MEASURES

Five alternative measures of marginal capacity cost are briefly outlined below and then subjected to simulation exercises.

PRESENT WORTH OF INCREMENTAL SYSTEM COST (PWISC)

Herrington [3] has argued that the PWISC represents the “best method” of calculating MCC because it is closest to Turvey's [15] ideal definition. The measure is defined as follows:

$$\text{PWISC} = \frac{\text{Present worth (PW) of system costs with one planned expansion} - \text{PW of system costs with different planned expansion}}{\text{PW of difference in quantities of output}}$$

The PWISC formula may be understood as follows: if capacity expansion could take place instantaneously and in “divisible” amounts, then the marginal (capacity) cost of an increment in output required by a development site would simply represent the cost of providing the extra capacity to facilitate exactly the output increase needed. But when capacity expansion is “lumpy” and contains many years worth of excess capacity, the problem becomes one of finding ways of allocating a lump-sum amount over the years until excess capacity is eliminated. Annuitizing the lump-sum amount equally over the number of years of excess capacity is one rational way of achieving this, and is appropriate if the take-up of excess capacity occurs at the same rate each year. If the take-up rate varies over the years to full capacity, then what is required is an annuity in a year which is proportional to the take-up rate in that year, and which still sums over all years to the lump-sum amount. In other words, what is required of the measure of marginal cost in a year is a constant amount, say X , which, when multiplied by the output in that year, and then discounted back to the present, for each of the years of excess capacity, will sum to equal the present worth of the planned investment (i.e. the lump-sum being allocated). In mathematical terms, the amount of the present worth of the planned investment (I) to be allocated to any year (t) of excess capacity is:

$$A_t = \frac{X \cdot O_t}{(1+i)^t} \quad (1)$$

where A_t = the amount of the lump-sum cost of investment expenditure allocated to year t ;

$X (=MCC)$ is a constant amount expressed in dollars per unit of output;

O_t is the demand for the output of the infrastructure service in year t ; and,

i is the discount rate.

The amount X is calculated such that when summed over all years of excess capacity, $t = i, \dots, j$, the result equals the present worth of the investment expenditure. If, for clarity, we substitute MCC for X , then we get:

$$\sum_{t=1}^j \frac{MCC \cdot O_t}{(1+i)^t} = PW(I) \quad (2)$$

Since MCC is a constant, Eq. (2) can be rearranged as:

$$MCC \sum_{t=1}^j \frac{O_t}{(1+i)^t} = PW(I)$$

and since $PW(O) = \sum_{t=1}^j \frac{O_t}{(1+i)^t}$, Eq (2) becomes:

$$MCC = \frac{PW(I)}{PW(O)} \quad (3)$$

One advantage of annuitizing the cost of I is that the interest (or “holding”) costs of the excess capacity fall equally on all developers regardless of whether they arrive well before, or close to the end, of the period of excess capacity. Moreover, the unit of demand for output (O) is not expressed directly in terms of the units of use (such as mega litres of water) but in terms of a “standard residential unit” (SRU) or an “equivalent tenement” (ET) or some equivalent measure. As a pragmatic device for calculating PWISC, an output increment (or SRU increase) can be postulated of a size sufficient to bring forward by one year the planned investment program. The numerator in PWISC then becomes the difference between the present worth of each investment stream and the denominator is the “present worth” of the postulated output increment.

ADJUSTED AMORTIZATION METHOD (AAM)

Parmenter and Webb [8] have suggested a somewhat different approach inspired by Turvey [14] when he observed that “since in the absence of system interdependence, marginal cost equals the first-year unit running cost of new

capacity plus its first-year amortization per unit of output, it is clear that first-year amortization epitomizes the complex of expectations and calculations about the future which are central to the notion of marginal cost", thus, "in principle, an intelligent guess at first-year amortization could furnish a quick route to an intelligent guess at marginal cost". When adapted to developer charges, this method involves four steps:

1. Estimate the economic value of the asset based on current estimates of the period to full take-up of capacity;
2. Amortize the resultant value over the same period. If a constant annual take-up rate represents a reasonable assumption, then a constant annuity is calculated. If it is known that something other than a constant rate is likely, then an annuity which is weighted in this manner can be calculated;
3. Calculate a constant developer charge per unit of output. For example, \$X per *SRU*, by dividing the constant annuity by the *SRU* take-up rate if the latter is assumed constant, or by dividing the present worth of the value of the asset by the present worth of the number of *SRU* *s*, (i.e. $PW(I)/PW(O)$ as in Eq. (3) above if the take-up rate is not constant). This method will produce a charge of \$X per *SRU* which will be equal for all developers irrespective of when they arrive to take-up a share of capacity; and,
4. Monitor the asset value regularly for unanticipated changes in future costs or demand, and exercise broad judgment in adjusting asset values accordingly. Then recalculate the charge per *SRU*.

There are at least two reasons why the simulation results calculated here will underrate AAM compared to other measures of marginal cost. Firstly, the calculation of AAM for the simulation uses the initial value of the cost of the current expansion program as the economic value of the asset and does not attempt step (4) above. The subjective element in step (4) is not something that can be objectively simulated; but leaving this step out does have a useful purpose in that it demonstrates by how much AAM will deviate from alternative methods of measuring MCC, if costs do change in the future. Secondly, the simulation (in effect) assumes only one large headworks asset that requires expansion from time to time. AAM is a method that lends itself to separate calculations of amortization for each type of asset. Because of this it will, in practice, reflect more accurately the cost of the individual assets on which a development will draw, compared to other methods.

AVERAGE INCREMENTAL COST (AIC)

Both the OECD (Herrington [3]) and the World Bank (Saunders [12]) have employed AIC defined as follows:

$$\text{AIC} = \frac{\text{The present worth of the least cost investment expenditures (those sensitive to quantity of water use)}}{\text{The present worth of the incremental output resulting from this investment stream}}$$

In the specific circumstances of developer charges, “incremental output” will be measured in output units (such as *SRUs* or *ETs*). AIC does require knowledge of a least-cost stream of forward investment, but not the two alternative streams required by PWISC. By its nature this method “smooths out” lumps in planned capital expenditures. In sum, it is an average cost for all planned capacity expansions.

METHOD SUGGESTED BY SYDNEY WATER CORPORATION (SWC)

The Sydney Water Corporation has produced an SWC method of calculating developer charges, especially when it is not administratively feasible to separate assets and attribute them to specific geographic areas. The SWC method lumps all output sensitive capital expenditures together for both past and future investment, and averages out the costs of capacity expansions over a lengthy period. The method is the same as AIC except that past trends are included in the charge in addition to estimated future costs. From a theoretical point of view the inclusion of past trends is somewhat surprising since prices or charges should signal future rather than past trends.

TEXTBOOK LONG RUN INCREMENTAL COST (TLRIC)

Where there are no extended plans and estimates of expansion costs of the whole system, both the OECD (Herrington [3]) and World Bank (Saunders [12]) suggest the use of TLRIC. The MCC component of TLRIC can be defined as follows:

$$\text{TLRIC} = \frac{r \cdot I_k}{O_{k+1} - O_k} \quad (4)$$

where I_k is the cost of the next major lump of investment; r is the capital recovery factor (equal to the annuity that will repay a \$1 loan over the period to full capacity with compound interest equal to the opportunity cost of capital on

the unpaid balance); and O_k, O_{k+1} represent output (e.g. *SRUs*) produced in year k and year $k+1$ respectively. Thus, during the years through to k , the TLRIC formula in Eq. (4) remains constant and reflects the annual equivalent of the MCC for the *next* lump of investment. As soon as that investment has taken place, k is redesignated to the subsequent large lump of investment. In one sense, TLRIC might be envisaged as a “mirror image” of AAM; since whereas AAM annuitizes current asset value based on assessments of future cost conditions, TLRIC takes the estimate of the cost of the next investment and annuitizes it “back” to the present day. Charges calculated using TLRIC would “jump” (or drop) immediately following an expansion of capacity depending on the per unit capacity cost of expansion.

MONTGOMERY WATSON (MW) METHOD

The MW method is a typical example of a method that is often recommended to municipalities by private consultants. This genre of methods can be summarized in the following five steps [6]:

1. Identify the assets requiring extension in order to service a development site and cost the necessary amplification works (e.g. say, \$400,000 worth of capital works);
2. Recognize that amplification works should contain an excess capacity component for later development, determine the share of the capacity of the asset required by the developer under consideration (e.g. 50 *ETs* of an ultimate capacity of 290 *ETs*);
3. Council should then determine “a period of cost recoupment” (e.g. 17 years);
4. Decide on an appropriate interest rate and calculate an annuity which repays the capital cost over the period of recoupment. For example, if the capital cost is \$400,000, the interest rate, i , is 8% and the period of recoupment is 17 years, the annuity, A , is calculated as:

$$A = \frac{400,000(0.08)}{1 - (1+0.08)^{-17}} = \$43,852 \quad \text{and,}$$

5. Determine the developer's share of payments by working out what proportion of repayments are directly attributable. For example, 50/290 (17) = 2.93 (two full repayments and 0.93 of a third). The developer's share is then calculated as follows [6]:

$$\begin{aligned} DC &= (1.08^{-1}) \cdot 43852 + (1.08^{-2}) \cdot 43852 + 1.08^{-3} \cdot (.93)(43852) \\ &= \$100,574 \end{aligned}$$

One problem with this method compared to the other methods discussed so far is that the developer charge per *ET* will vary depending on the number of *ETs* a developer takes up; the larger the number of *ETs*, the smaller the resultant charge per *ET*. For instance, in the example above, the developer taking up 50 *ETs* will pay a per *ET* charge of \$2201, whereas the developer who takes up 17 *ETs* in this development pays \$2580 per *ET*. An additional problem is that the constant annuity (\$43,852 in the example) includes a component for interest that would accumulate over the 17 years calculated on the assumption that developers take-up capacity at a constant rate over that period. If development does not take place at a constant rate (because, say, one developer comes in immediately and buys 80% of the capacity), then the interest burden to be spread amongst developers is likely to be much lower overall. In this respect, the holding costs imposed on developers are thus somewhat arbitrary.

THE SIMULATION MODEL ASSUMPTIONS

Key assumptions in the simulation model that will be used to compare alternative measures of MCC are set out in TABLE 1. The model itself spans a hypothetical period of 30 years from 1987 to 2016. The "current" year is 1997 (year 0). Measured in *ETs*, the rate of output grows annually at an average rate of \$500 a year (column (3)). Up to 1997, this has been met by an initial investment in 1987 that has facilitated 5000 *ETs* of growth but further expansion is required in 1997. A least-cost stream of future investment has been determined which includes expansions in 2003, 2006 and 2016, in addition to 1997. The costs of each expansion (indicated in columns (4), (5) and (6)) are presented in constant 1987 dollars. For simplicity, it is assumed that there is no growth in demand for service from existing development. That is, all of the capacity expansions are required to meet demand from new development so that it is not necessary to apportion out sections of capacity to meet existing development. A real interest rate of 5% is assumed initially in the simulation.

TABLE 1: Simulation Model Assumptions

Year	Capacity In ETs	Annual Average ET Growth Rate	At Constant Costs ^{a,d}	At Increased Costs ^{b,d}	At Decreased Costs ^{c,d}
(1)	(2)	(3)	(4)	(5)	(6)
1987	\$5000	\$500	\$10,000,000	\$9,000,000	\$10,000,000
1988		\$500			
⋮					
1996		\$500			
			Future Investment		
1997	\$3000	\$500	\$6,573,254	\$6,573,254	\$5,915,929
1998		\$500			
1999		\$500			
⋮					
2002		\$500			
2003	\$1500	\$500	\$3,526,731	\$3,879,403	\$2,856,652
2004		\$500			
2005		\$500			
2006	\$5000	\$500	\$10,000,000	\$12,100,005	\$7,290,004
2007		\$500			
⋮					
2015		\$500			
2016	\$1500	\$500	\$3,526,731	\$4,694,081	\$2,321,732

- a Investment at constant costs in this simulation means that each time capacity is expanded the per unit costs of expansion (construction of assets plus interest costs) are exactly the same as for the previous expansion.
- b Per unit costs of expansion (including interest costs) rise by 10% each time expansion takes place.
- c Per unit costs of expansion (including interest costs) fall by 10% each time expansion takes place.
- d Investment expenditures are expressed in constant 1987 prices.

Alternative measures of MCC are compared under three scenarios. Firstly, in the constant cost case, each time an expansion of capacity takes place, the total capital costs of that expansion (i.e. construction costs and the interest costs that will be incurred until capacity is exhausted) are such that per unit costs remain constant (column (4)). In other words, the annuity that will repay each of

the investments indicated over each period to full capacity is constant (at \$1,295,046) each year. Second, in the increasing cost case, total capital costs rise by 10% each time expansion of capacity takes place. Thirdly, in the decreasing cost case, total capital costs fall by 10% with each capacity expansion. (Details on calculations are contained in the Appendix.)

It is also assumed for clarity in the simulation exercise that headworks assets can be aggregated so that they appear to be one major asset that requires expansion in the clearly identifiable “jumps” indicated in TABLE 1. It is recognized that in reality headworks systems will have multiple assets that will require expansion at varying times. However, a more realistic depiction of this feature would obscure the discrete increases that are required in the simulation in order to compare qualitative differences between methods (i.e. those dealing only with the next “jump”; those which average out the “jumps”, etc.).

SIMULATION RESULTS

The developer charges per *ET* that result from each of the different measures under the constant costs, increasing cost and decreasing cost assumptions are shown in TABLE 2. With the exception of the MW method (calculated as a per *ET* charge for 20 lots), all charges calculated under constant costs turn out the same at \$2590 per *ET*. This result arises because, under constant costs per unit, costs will not vary over time and averages and marginals will always be equal. That is to say, even though each of these measures “searches out” and gives different emphasis to different periods over the 30-year time period, if costs over all periods are everywhere the same, the measures must coincide.

TABLE 2: Developer Charges Calculations (Per *ET*) Under Constant Costs, Increasing Costs and Decreasing Costs Assumptions

MCC Measures	Charges Under Constant Costs	Charges Under Increasing Costs	Charges Under Decreasing Costs
(1)	(2)	(3)	(4)
PWISC	\$2590	\$3261	\$1817
AAM	\$2590	\$2590	\$2331
AIC	\$2590	\$2858	\$2109
SWC	\$2590	\$2589	\$2355
TLRIC	\$2590	\$2849	\$2098
MW	\$2467	\$2467	\$2220

When costs steadily increase over time, the charges calculated by each method begin to diverge (TABLE 2, column (3)). PWISC is the measure which best signals that future development costs in an area will be higher (and hence development should weigh these costs against alternative areas that are cheaper). AIC and TLRIC come closest to PWISC, although both are about 12% short of PWISC, and AAM and SWC are some 21% lower than PWISC. The latter feature arises because, as we saw earlier, AAM is left unadjusted for future trends. SWC is lower because it takes in an earlier period when costs were substantially lower. It is interesting to note that if a simple "broad judgment" rule is applied to AAM then AAM will perform as well as TLRIC. For example, the rule could be "if the most recent valuation of the asset has not anticipated it, then raise the developer charge 10% when costs of the next expansion of capacity are expected to rise 10%. (Increasing AAM by 10% calculates a charge equal to that of TLRIC).

In the decreasing cost scenario (TABLE 2, column (4)), AAM and SWC are again the least effective in signalling that costs in development area are falling. AIC and TLRIC provide "better" signals, (and are within 16% of PWISC). However, once again a broad judgment rule could be applied to AAM: "if the most recent asset valuation has not anticipated it, then lower the developer charge by the same amount that costs in the next investment are expected to fall". This again would produce better results for AAM, matching it to TLRIC.

The two scenarios are useful in that they enable a judgment to be made about which measures will err in what direction, given an expectation about the future, and perhaps even enable a ranking to be determined about the extent to which each will deviate relative to the others. One question that naturally arises is what is the most likely scenario in real-world circumstances? It is, of course, true that future technologies tend to lower costs per unit. However, it is interesting to note that notwithstanding this offsetting factor, there are some recent commentators who believe that average costs of supplying infrastructure, such as water services to urban areas, may well rise over time [7]. For example, Rees [10] observed "it is now being recognized that the marginal costs of providing new water supplies will increase markedly in the next decade or so, because the period of low cost source extraction is now at an end". If these views are correct, and TABLE 2, column (3) is the likely scenario, then all alternative methods of calculation will understate the MCC as indicated by PWISC.

SENSITIVITY TESTS

Each of the measures of MCC was subjected to sensitivity tests in the key parameters affecting their calculation. The results of these sensitivity tests are discussed below.

SENSITIVITY OF MCC MEASURES TO CHANGES IN INTEREST RATES

The results of changes in the real rate of interest are presented in TABLE 3. The first parameter change considered was a 20% increase in the real rate of interest, from 5% to 6%, using the same cost figures as were employed in the constant cost simulation (TABLE 1, column (4)). The effect on the charges calculated by each measure was small, ranging between increases of 3.3% and 4.3%. Increases of similar limited magnitude occurred when the investment figures were substituted for the increasing cost simulation. Compared to the same charges calculated for 5% (TABLE 3, column (4)), the effect of a 20% rise in the rate to 6% was still marginal (TABLE 3, column (5)).

TABLE 3: Developer Charges Calculations^a Under Varying Real Interest Rates - Selected Scenarios

MCC Measures	5% Constant Cost	6% Constant Cost	5% Increased Cost	6% Increased Cost	10% Constant Cost
(1)	(2)	(3)	(4)	(5)	(6)
PWISC	\$2590	\$2668	\$3261	\$3331	\$3030
AAM	\$2590	\$2674	\$2590	\$2674	\$3019
AIC	\$2590	\$2685	\$2858	\$2952	\$3061
SWB	\$2590	\$2702	\$2589	\$2678	\$3188
TLRIC	\$2590	\$2673	\$2849	\$2902	\$3018

^a Charges are calculated per ET.

A second interest rate test raised the real rate further, from 5% to 10%. This had a greater effect on the charges calculated, but overall, a 100% increase in the interest rate increased the charges by between 17 and 23% (TABLE 3, column (6) compared to column (2)).

Further tests revealed that the sensitivity of MCC measures with respect to interest rates rose according to two factors. The first of these is the size of the rate before the change; that is, the higher the original rate, the higher the sensitivity of charges to changes in this rate. For example, doubling the rate

from 5% to 10% produced changes in the calculations averaging around 18%. A further doubling of the rate of 10% to a real rate of interest of 20% produced an increase in AAM of 31%, although by contrast increases in PWISC and TLRIC, for instance, were still quite small at around 11%. In explaining why AAM moved further than the other measures, it is clear that PWISC and TLRIC draw on future trends more than AAM (since step (4) of AAM is not attempted). Since these other measures draw on what is happening to interest costs in the future, it is apparent that because of the shorter period to full capacity of the next investment expansion (\$3,526,731 for three years, as in TABLE 1, column (4) compared to six years for the 1997 expansion on which AAM draws) the lower interest burden compared to the 1997-2002 period reduces the sensitivity to interest rate changes of these measures.

The second factor increasing the sensitivity of charges to alterations in the interest rate is the length of the excess capacity period. If the costs for the 1997 expansion of \$6,573,254 are spread over a period to full capacity of six years, then doubling the real interest rate from 10% to 20% will produce a change in AAM of 31%. On the other hand, if that same capital cost is spread over 15 years, then doubling the interest rate from 5% to 10% causes a rise of 63% in AAM.

High real interest rates combined with long periods to full capacity indicate a greater sensitivity of the AAM charge to interest rates than is apparent with the excess capacity periods used in the simulation. The same would be true of the other measures if the investment streams simulated had had significantly longer periods to full capacity.

The higher sensitivity to interest rate changes at high real rates combined with long excess capacity periods arises because the interest burden of holding excess capacity for many years starts to become a significant factor in overall capital costs. In choosing the optimal scale of expansion, the economies of scale of larger capacity need to be weighed, amongst other things, against the higher interest burden of long periods of unused capacity. In examining various types of developer charges in the United States, Peiser [9] observed that the high holding costs of long periods of excess capacity may have been overlooked. Peiser [9] argued that "while the results depend on the particular assumptions, they demonstrate that economies of scale must be substantial for users to realize net benefits" and thus his results "suggest that planners should temper traditional engineering approaches in favor of larger systems to take advantages of economies of scale; they need to understand the costs for carrying excess capacity".

In sum, the interest rate sensitivity tests appear to suggest that the “extreme sensitivity” requires unusually high interest rates combined with long periods of unused capacity. Over shorter excess capacity periods and lower real rates of interest there is much less sensitivity of charges to changes in interest rates, and little variation between the alternative measures in the extent to which they demonstrate this conclusion. If high real rates of interest do prevail and periods of excess capacity are longer than, say, 15 years, holding costs become a significant component of expansion costs and must be weighed against the benefits of economies of scale in large investment programs.

SENSITIVITY OF MCC MEASURES TO CHANGES IN ASSET VALUATIONS

A second series of sensitivity tests examined the effect on charges of variations in the valuations of headworks assets on which the calculations are based. Using the investment cost figures for all three scenarios of constant cost, increasing cost and decreasing cost, all assets were devalued 40%. The results are presented in TABLE 4.

The results in TABLE 4 show that irrespective of whether costs are constant, increasing or decreasing over time, a change in asset value leads to a directly proportionate change in the charge calculated by all measures.

SENSITIVITY OF MCC MEASURES TO CHANGES IN THE LOT TAKE-UP RATES

In a further series of sensitivity tests, the effects on charges of changes in the rates at which developers take-up lots (measured as *ETs*) were examined. In the first test, lot take-up rate was halved as from 1997. In effect this means that in the simulation, annual output each year from 1997 is halved and the periods to full capacity are doubled. In the second test, the lot take-up rate was doubled. This has the converse effect in the simulation; annual output each year is doubled, and the periods to full capacity are halved. The results of these simulations are presented in TABLE 5.

In TABLE 5 all charges rise as a result of a 100% fall in the rate of development since the holding costs of longer periods to full capacity are now proportionately greater. However, it is again somewhat surprising how small the effect of a dramatic drop in the lot take-up is on the developer charges (TABLE 5, column (2) compared to column (3)). AAM moves up the most (by 15%) and AIC is second at 13%. Both these measures are most affected by the (now) 12-year period to full capacity of the 1997 investment. PWISC and TLRIC are most influenced by events in the 2003 investment period (now a six-year period) where the holding costs are proportionately less, whilst SWC is least affected because it draws significantly on a period where no change occurs.

TABLE 4: Developer Charges Calculations^a Under Various Asset Devaluations

MCC Measures	40% Devaluation Constant Costs	100% Asset Value Constant Cost	40% Asset Value Increasing Cost
(1)	(2)	(3)	(4)
PWISC	\$1554	\$2590	\$1956
AIM	\$1554	\$2590	\$1554
AIC	\$1554	\$2590	\$1715
SWB	\$1554	\$2590	\$1553
TLRIC	\$1554	\$2590	\$1703

MCC Measures	Charges at 100% Asset Value - Increasing Costs	Charges at 40% Asset Devaluation - Decreasing Costs	Charges at 100% Asset Value - Decreasing Costs
(1)	(5)	(6)	(7)
PWISC	\$3261	\$1090	\$1817
AIM	\$2590	\$1399	\$2331
AIC	\$2858	\$1265	\$2109
SWB	\$2589	\$1413	\$2355
TLRIC	\$2849	\$1259	\$2098

^a Charges are calculated per *ET*.

TABLE 5: Developer Charges Calculations (Per *ET*) Resulting From Variations in the Rate of Development

MCC Measures	50% Constant Cost	100% Constant Cost	200% Constant Cost
(1)	(2)	(3)	(4)
PWISC	\$2779	\$2590	\$2529
AAM	\$2967	\$2590	\$2439
AIC	\$2921	\$2590	\$2422
SWC	\$2695	\$2590	\$2495
TLRIC	\$2779	\$2590	\$2529

SENSITIVITY OF MCC MEASURES TO A NON-CONSTANT
ANNUAL DEVELOPMENT RATE

The final simulation tested for the effect on charges of a varying annual take-up rate, holding constant the period to full capacity. The scenario assumed that 75% of the lot take-up occurs in the first third of the period to full capacity. The results are shown in TABLE 6.

The effects of this simulation are very similar to those of a doubling of the rate of development (TABLE 5 Column (4)). The charges fall slightly, with AIC showing the largest decline (7%). Once again, the variation between measures is relatively small.

**TABLE 6: Developer Charges Calculations Resulting
From Non-constant Annual Development Rate**

MCC Measures	Charges when 75% of Lot Take- Up Occurs in the First Third of the Period to Full Capacity Constant Cost Investment Figures	Charges at the Annual Average of 500 ETs Constant Cost Investment Figures
(1)	(2)	(3)
PWISC	\$2512	\$2590
AAM	\$2439	\$2590
AIC	\$2404	\$2590
SWB	\$2495	\$2590
TLRIC ^b	\$2590	\$2590

CONCLUDING REMARKS

The simulation results show that if the costs of future expansion of infrastructure service capacity are not expected to be significantly different from those of the past, any of the measures will provide an acceptable estimate of marginal capacity cost. This is because, given accurate data, all methods must coincide when per unit costs are constant. Even in circumstances where costs are not constant, it is still possible to argue that any of the methods might provide an acceptable “ball park” estimate (with some adjustment) of MCC because where they do diverge from PWISC they do so in a predictable way, so that bias could be corrected. The possible exception to this occurs with SWC where we have argued that the “backward-looking” component of this measure be removed. When scenarios of either rising average costs or falling average costs are

modeled, the measures that are least “forward looking” do worst. As to which of the constant costs, rising costs or falling cost scenarios are most likely to obtain in real-world circumstances, the arguments of some recent commentators (e.g. Neutze [7], Rees [10] and Herrington [4]) that water supply costs may rise in the future seem plausible. If this is true, then our results indicate that all alternative methods will understate marginal capacity costs of supplying the service compared with PWISC. If the average costs of future expansions fall, all measures will overstate the appropriate charge and would have to be adjusted downwards.

If we discard SWC because of its backward-looking focus, and compare AAM to TLRIC and AIC, then several reasons emerge for recommending AAM as the most effective and practical option. First, it can achieve at least the same degree of accuracy of estimation of MCC as TLRIC. Secondly, AAM can measure the MCC of individual assets that are specific to a site. A method such as AIC tends to average the forward investment plans over a wide area and hence average out some locational variation in costs. Thirdly, there is the pragmatic consideration that TLRIC and AIC (and of course PWISC) all require reliable forward estimates of the costs of capacity expansion. On the other hand, AAM can avoid this demand for detailed data by using only broad judgment about future costs and demand conditions. Fourthly, the AAM approach can be used to calculate charges for distribution assets as well as headworks and major works. Since distribution assets tend to have a smaller excess capacity and demand for these services is not expected to grow indefinitely (requiring capacity expansions), AIC and TLRIC cannot be applied. Finally, with AAM, the interest rate burden over the expected period to full take-up of capacity is spread evenly over all developers. Early developers gain no interest cost advantage, but neither is development stifled by higher interest costs later on.

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APPENDIX I

EXAMPLES OF METHODS OF CALCULATION OF DEVELOPER CHARGES UNDER ALTERNATIVE MCC MEASURES

The calculations commence by computing an annuity sufficient to repay each investment over the period to full capacity of each, using the following formula (see, for example, Ross [11]):

$$A = \frac{I(i)}{1 - (1+i)^{-t}}$$

where A is the annuity amount;

I is the cost of the investment;

i is the real rate of interest (assumed to be 5.00% per annum except for interest rate sensitivity tests); and,

t is the period to full capacity use of the investment.

For example, \$10 million headworks assets invested in 1987 amounts to an annual equivalent of \$1,295,046 over the ten years to full capacity of this investment. For the "constant cost" case in the simulation, the construction and interest costs combined of each future expansion was assumed to remain at an annual equivalent of \$1,295,046. Hence the six-year period of investment from 1997 required an investment amount of \$6,573,254, and the three-year period of investment from 2003 required an amount of \$3,526,731 to ensure constant costs (at \$1,295,046 annually).

To impose an increasing costs scenario, each time a capacity expansion was required, starting from \$9 million in 1987 (annuitizing to \$1,165,541) a 10% increase in the annuity was assumed. This meant, for instance, that the 1997 expansion was set to \$6,573,254 (annuitizing to \$1,295,046, which is 10% higher than \$1,165,541); the 2003 expansion was set to \$3,879,403 (annuitizing to \$1,424,550, which is 10% higher than \$1,295,046 and the 2006 expansion was set to \$12,100,005 (annuitizing to \$1,567,006, which is 10% higher than \$1,424,550).

To impose a decreasing costs scenario, each time a capacity expansion was required after the \$10 million 1987 investment, a 10% decrease in the annuity was assumed. This meant, for example, that the 1997 expansion was \$5,915,929 (annuitising to \$1,165,541) and the 2003 expansion cost \$7,290,004 (annuitising to \$944,088).

For the constant costs scenario, the individual measures were calculated as follows:

$$PWISC = \frac{\text{Present worth (PW) of system costs with one planned expansion} - \text{PW of system costs with a different planned expansion}}{PW \text{ of the difference in quantities of output}}$$

An output increment of 500 was assumed, sufficient to necessitate the investment program to move forward by one year. The only difference between the present worth of the investment stream with and without this increment, will be that an additional \$1,295,046 will be required in period 5. Hence:

$$\frac{PW \text{ of } 1,295,046 \text{ in period } 5}{PW \text{ of } 500 \text{ in period } 5} = \frac{1,295,046/(1+i)^5}{500/(1+i)^5}$$

Developer Charge for PWISC = \$2,590 per *ET*

Calculating the charge for PWISC under increasing and decreasing costs required additional adjustments in later years because of differences in the annuities for each investment.

For example, PWISC under increasing costs required an additional \$1,424,550 in period 5, plus a difference of [\$1,567,006 – \$1,424,550] in period 8, plus a difference of [\$1,723,707 – \$1,567,006] in period 18.

$$AAM = \frac{\text{Present worth of an updated value of the current asset}}{\text{Present worth of output over the period to full capacity}}$$

At time $t = 0$ (1997), the updated value of \$6,573,254 is \$6,573,254. Thus:

$$AAM = \frac{6,573,254}{\frac{500}{(1.05)} + \frac{500}{(1.05)^2} + \dots + \frac{500}{(1.05)^6}} = \frac{6,573,254}{2537.9}$$

Developer Charge for AAM = \$2590 per *ET*.

Because the simulation assumes a constant rate of output of 500 *ETs* per year, an alternative calculation method for AAM is to divide the constant annuity for \$6,573,254 by 500:

i.e. Developer Charge for AAM = \$2590 per *ET*

$$AIC = \frac{PW \text{ of forward investment expenditures}}{PW \text{ of the output over that period}}$$

$$\begin{aligned} PW \text{ forward investment} &= \$6,573,254 + 3,526,731/(1.05)^6 + 10,000,000/(1.05)^9 \\ &= \$15,651,044 \end{aligned}$$

$$\begin{aligned} PW \text{ output} &= 500/(1.05) + 500/(1.05)^2 + \dots + 500/(1.05)^{19} \\ &= \$6042.7 \end{aligned}$$

$$AIC \text{ Developer Charge} = 15,651,044/6042.7 = \$2590 \text{ per } ET.$$

SWC:

$$\text{SWC} = \frac{\text{PW of all investment expenditure (past and future) (PW(I))}}{\text{PW of output over the whole period (PW(O))}}$$

The $PW(I) / PW(O)$ of the forward investment stream is calculated as in AIC

The $PW(I) / PW(O)$ of the past investment is calculated as:

$$= \frac{\$10,000,000 \times (1.05)^{10}}{500 \times (1.05)^9 + 500 \cdot (1.05)^8 + 500 \times (1.05)^7 \dots + 500} = \frac{16,288,946}{6288.6}$$

Adding together backward and forward components:

$$= \frac{15,651,044 + 16,288,946}{6042.7 + 6288.6} = \frac{31,939,990}{12331.3}$$

Developer charge for SWB = \$2,590 per *ET*.

TLRIC:

$$\text{TLRIC} = \frac{r \cdot I_k}{O_{k+1} - O_k} = \frac{\text{Annuitisation of the next lump of } I}{\text{Annual } ET \text{ output}}$$

The next lump of investment is \$3,526,731, which annuitizes to \$1,295,046 over a three-year period to full capacity:

Therefore, Developer charge for TLRIC = 1,295,046/500 = \$2,590 per *ET*.

MW:

The MW methodology is explained in the text.

For the increasing and decreasing cost scenarios the same procedures were followed using the altered investment figures as described above.

For the interest rate sensitivity tests the same procedures were again followed, except that the interest rate of $i = 0.05$ was replaced by $i = 0.06$ and $i = 0.1$ respectively.

For the sensitivity to changes in asset valuation using the constant cost investment figures, the sequence of investment costs of \$10,000,000 (10 periods); \$6,573,254 (6 periods); \$3,526,731 (3 periods); \$10,000,000 (10 periods) and \$3,526,731 (3 periods) were replaced by \$6,000,000 (10 periods); \$3,943,952 (6 periods); \$3,526,731 (3

periods); \$6,000,000 (10 periods); and \$2,116,039 (3 periods) respectively.

The increasing cost investment figures were also reduced by 40% in a second test of asset valuation sensitivity. For testing sensitivity to a halving of the lot take-up rate, the annual output was reduced to 250 *ETs* and the 1997 investment program became the equivalent of \$741,630 a year for 12 years and the 2003 investment program shifted to 2009, becoming the equivalent of \$694,828 over six years. The 2006 expansions program of \$10,000,000 was shifted to 2015, annuitizing to \$802,426 for 20 years. Doubling the lot take-up rate changed the annual output rate to 1000 *ETs* and brought forward all the expansion programs in an analogous manner. The calculations ceased at the end of 2007 because all the investment of the program had taken place by this date.

The simulation of non-constant take-up rates used output rates of 1125 for 1997 and 1998 and 187.5 thereafter to 2003; 1125 for 2003 and 187.5 for 2004 and 2005; 1250 for each of years 2006 to 2008 (inclusive) and then 178.5 thereafter for the next seven years. Annuities were then calculated which were weighted by these outputs each year. For example, the annuity for 1997 (where output is 1125 in that year) is:

$$\frac{PW(6,573,254)}{PW \text{ output over the six years to full capacity}} \times 1125 = 2439 \times 1125$$

$$\text{ANNUITY} = \$2,743,875$$

BIOGRAPHICAL SKETCHES

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