THE ECONOMIC APPRAISAL OF LAND-USE PLANS

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INTRODUCTION

1. This article outlines a procedure, derived from methods of transport appraisal, for evaluating land-use plans. Land-use planning involves the use of legal planning controls, direct government investment, and sometimes indicative planning to bring about a spatial configuration of activity. It is assumed for present purposes that the effects of these policies either are known with certainty or have predictable probability distributions. What is considered here is an economic framework for choosing between alternatives defined in terms of the policy instruments listed above. It is not a complete evaluation procedure; in particular it does not consider distributional issues, or make more than passing reference to uncertainty. The distributional aspects of shadow price revenue, in particular, raise complex theoretical issues. But these raise no problems in this context which have not been considered elsewhere.

2. The paper falls into four parts. After this introduction, the next section recapitulates briefly the operation of gravity models, principally in the context of transport planning. The third section describes the principles of benefit evaluation in the context of an “unconstrained” gravity model. This is roughly equivalent to the situation where there is government investment and indicative planning but no legal planning controls. The fourth part considers “constrained” gravity models, which represent the case where there are legal planning controls in addition.

Features of land-use planning

3. The main feature which distinguishes land-use planning from general planning is its spatial aspect. At one extreme, transport appraisal assesses improvements in mobility (and hence generalised accessibility) without reference to what is made nearer. At the other extreme, conventional appraisal of projects such as power stations ignores spatial aspects, and concentrates on the value of the project irrespective of its location. The methodology described here is mainly an attempt to integrate the two into the wider notion of accessibility. This wider notion was not necessary for

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227
transport evaluation, which assumes that the quality of land use in a given location does not change. We shall see that under these circumstances the methods described here reduce to the transport evaluation in [1].

4. Another important feature of land use planning is the use of legal controls: legal powers are used deliberately to prevent markets from reaching equilibrium. Thus, appraisal has to use shadow prices which represent the difference between what people would (in some generalised sense) be prepared to pay for a certain activity and what they are actually required to pay. The benefit measure at any point in time attempts to integrate three elements:

   (a) proximity—transport and location;
   (b) the quality of activities—other authority expenditures such as parks;
   (c) planning controls.

5. This benefit measure, as always, forms only one element of the appraisal. It is necessary to set this in both the spatial and the temporal context. The locations cover the whole area of the plan (including the “rest of the world”), activities cover in principle the complete range planned for, and time (also in principle) covers the time period of the plan plus a terminal state. Two alternative plans may differ in the nature, timing, and location of activities. In this way a complete comparison of plans is possible.

6. One further aspect of plans, upon which planners themselves have on occasion placed great emphasis, is flexibility. The system can also be used to appraise this in the following way. Instead of assuming planning for a known certain future, it may be assumed that events have a certain probability distribution. The results of planning decisions will then themselves have a probability distribution. In principle, then, we may measure the “expected” benefit arising from a given set of planning decisions. This will generally be different from the benefit of the most likely outcome. The mark of an inflexible plan will be a bimodal distribution of outcomes, with a finite probability of a very bad outcome. In that case the “expected” benefit will be lower than the benefit of the most likely outcome, given the relatively high possibility of a poor outcome if the plan breaks down. Flexible plans will tend to show “expected” benefit close to the benefit of the most likely outcome. The other special aspect of planning decisions is that they represent self-conscious interference with the market. The comparison of plans thus involves the comparison of “non-market-clearing” situations. As we shall see, this involves the use of shadow prices to represent these disequilibria. These must also be incorporated into the benefit-measuring system.

7. The procedure involves taking the alternative land-use/transport plans to be compared, and using a gravity model to estimate the shadow prices of the constraints on activity implied by each plan. (These constraints are essentially “supply curves” for activities such as dwelling, employment, etc. Different land-use policies are represented by adding a shadow price to supply curves.) With this model it is possible to estimate proximity benefit in the form of a consumer’s surplus, as in transport. From trade-off relations obtained elsewhere it is possible to place values on different living and working environments. Although this process is separable from the proximity benefit, it is essential for both processes to be performed; otherwise, for example, more proximity will always appear as a benefit without the possibly compensating dis-benefits of higher density, etc.
TRANSPORT MODELLING PROCESS

8. The following discussion contains many references to transport modelling. For the sake of completeness it seems sensible therefore to describe briefly the structure of a transport model, and in particular a gravity model. At the start of the modelling process, data is collected about such things as numbers of resident households by zone, car ownership, employment, and so on. This is input to the trip generation model, which determines the number of trips that will be generated by each zone of the study area \((O_i)\) and also the numbers attracted to each zone as destinations \((D_j)\). These are referred to, somewhat obscurely, as trip ends. In the distribution model, the number of trips from zone to zone is estimated as a function of the trip ends (produced by the generation model) and a measure of spatial separation—conventionally this is distance with either time or speed. The distribution model discussed in this paper is an exponential gravity model in general use. (The principles apply to non-exponential gravity models, but the practice is much more difficult.) It is of the form:

\[
T_{ij} = a_i O_i b_j D_j e^{-\lambda C_{ij}}
\]  

where

- \(T_{ij}\) = number of trips between zones \(i\) and \(j\)
- \(O_i\) = number of trips originating in zone \(i\)
- \(D_j\) = number of trips ending in zone \(j\)
- \(C_{ij}\) = generalised cost of such a trip
- \(e^{-\lambda C_{ij}}\) = trip decay function.

These models are either singly constrained, when \(\Sigma_j T_{ij}\) is required to equal \(O_i\) or \(\Sigma_i T_{ij}\) to equal \(D_j\), or fully constrained, where both requirements must be met.

9. It would be fruitful at this stage to consider the economic implications of using constrained gravity models, for much of the succeeding discussion will then become clearer. As an example, assume a zone (called zone \(i\)) of rented dwellings. The demand for living in that zone is a function of the "generalised" cost of living there. This includes rental, quality of housing, and so forth, but does not include proximity. Thus in Diagram 1 the marginal cost curve intersects the demand curve \(D_1\) on line \(Q_1\). If accessibility is improved, the demand curve will shift to \(D_2\). However, when constrained gravity models are used the underlying assumption is that the level of demand remains at \(Q_1\), which implies that the marginal cost curve is vertical and not as drawn: that is to say, the effects of an improvement in accessibility are taken up in increased rents and shadow costs.

EVALUATION OF LAND USE CHANGES WITH AN UNCONSTRAINED GRAVITY MODEL

10. The concept behind the evaluation method discussed in this paper is that of consumer surplus. As far as land use plans are concerned, one imagines that the utility derived by an individual from locating in a given area will be a function of the "niceness" of that area and the proximity of that area to various activities, such as employment, shops and theatres. If the quality of the destinations is taken
into account, we call the composite term "accessibility". If the form of the accessibility utility function is known, then, in principle, the appropriate demand and surplus function can be derived, and the difference in surplus between the two plans can be measured. This paper suggests how this might be achieved.

11. The essence of the approach is that it assumes that a gravity model, such as the one described in paragraph 8, is a traditional demand function for trips. Under that assumption it is possible to derive the underlying utility and surplus functions; the net benefit of one plan over another is simply the difference in surplus between the two plans. However, there is a problem, because a constrained gravity model is not, strictly speaking, a demand function. For the moment, therefore, an unconstrained model, which represents the demand function, will be considered:

\[ T_y = k e^{-\lambda(C_y + \gamma_i + \eta_j)} \]  

(2)

where \( T_y \) = trips from zone \( i \) to zone \( j \)

\( C_y \) = behavioural cost per unit of a trip from zone \( i \) to zone \( j \)

\( \alpha_j \) = inherent attractiveness of zone \( j \)

\( \gamma_i \) = inherent generative qualities of zone \( i \)

\( k \) = trip rate.
THE ECONOMIC APPRAISAL OF LAND-USE PLANS

H. Neuberger and J. Wilcox

The terms \( a_j \) and \( \gamma_i \) will be more fully described later, but it should be noted that they should not be confused with the terms \( a_j \) and \( b_j \) in the fully constrained gravity model. From the demand function (equation 2) a surplus function can be derived, as follows:

\[
S = \Sigma j k e^{-\lambda(C_{ij}+\gamma_i+b_j)} dC_{ij}
\]

(integral of equation 2)

\[
S = \frac{k}{\lambda} \Sigma y e^{-\lambda(C_{ij}+\gamma_i+y)}
\]  

(3)

12. Land use changes when an area becomes a centre for industrial development, or when a new town is built; many more examples could be given. Clearly, land use changes may arise for any of a number of reasons, such as government policy, discovery of natural resources, or perhaps an improved transport network. The methods described here are suitable for evaluating any land use change, however it is brought about. It should be noted, however, that these methods are evaluating different arrangements for the same set of people. For this reason, in a comparison of two land use plans the population should be the same. This is not a serious restriction, for if the population is not the same the study area should be enlarged until it is. So, if one were looking at, say, a small part of London which as a result of planning activity was to have a much larger population, that small district could not be the study area; but, if it was thought that the population increase would come from the rest of London, London as a whole could be taken as the study area.

13. We must now explain why this method measures accessibility. Accessibility may be viewed simply as proximity, or it may be considered to subsume both proximity and attractiveness. To take a very simple example, assume a study area of zones \( i \) and \( j \). Zone \( i \) has a population of five with two jobs. Zone \( j \) has three jobs. It takes two minutes to travel within zone \( i \), ten minutes to travel to zone \( j \). One could define an average proximity of available jobs to a given prospective employee as the sum of the distance to the various jobs divided by the number of available jobs. In this case the number of jobs would be represented by \( D_i \) and \( D_j \), two and three respectively. Alternatively, one could further weight this average by taking into account the fact that one zone is intrinsically more attractive as a work place than another. In this case, \( D_i \) and \( D_j \) should be replaced by \( e^{-\lambda a_i} \) and \( e^{-\lambda a_j} \), since \( a_j \) was defined earlier as a measure of the inherent attractiveness of a zone as a destination. If work trips are being considered, \( \gamma_i \) will be a measure of the residential quality of zone \( i \) and \( a_j \) the desirability of zone \( j \) as a workplace. It is this latter approach which is implicit in the use of equation (3).

14. Under either definition of accessibility, an improved road between zones \( i \) and \( j \)

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1 A corresponding "utility function" (at constant marginal utility of money) is derived in [1] as:

\[
U = \frac{-1}{\lambda} \Sigma y (T_{ij} \log T_{ij} - (l-k) \lambda T_{ij}) - \Sigma O_i \gamma_i + \Sigma J_i D_j a_j
\]

where \( O_i \) = number of trips originating in zone \( i \)
\( D_j \) = number of trips ending in zone \( j \)

For the relation between the utility function in the constrained and unconstrained models, see [1]. It should be noted that this utility function is an aggregate of all utility functions. However, there is a further discussion of this point in para 16. These utility functions are in money terms; this avoids problems about the marginal utility of money [2].

231
would improve accessibility. Under the second definition accessibility would also be changed by a land use change involving, say, the building of a swimming pool for employees or an improvement in quality of jobs in zone \( j \), since there would be a change in \( e^{-3y_{ij}} \). Likewise a new factory in zone \( j \) would affect accessibility, since there would be a change in the number of trips ending in zone \( j \). Thus, if one regards the surplus function (equation 3) as an aggregate accessibility index (the terms \( e^{-3y_{ij}} \) and \( e^{-3c_{ij}} \) represent “niceness”, \( e^{-3c_{ij}} \) represents proximity), the surplus function will respond to any change in accessibility, whether achieved through land use changes or through transport improvements.

15. The terms \( \alpha_j \) and \( \gamma_i \) which appear in equations 2, 3 and 4 have been defined as the inherent attractiveness of a zone. Paragraphs 13-14 may have given an intuitive idea of what \( \gamma_i \) and \( \alpha_j \) mean, but not how values may be assigned to them. This is an area for further research, but it is possible at this stage to put forward an example of the type of solution looked for. The \( \gamma_i \) will be dealt with first. J Stuart Wabe [3] has studied house prices as a means of establishing the value of journey time, the rate of time preference and the valuation of some aspects of environment in the London Metropolitan Region. This study used regression analysis to explain house prices as a function of, among other things, journey costs, social class of area, population density and proximity to the green belt. This may be represented by the following equation:

\[
V = a + b\bar{J}_i + cSC_i + gPD_i + hGB_i
\]

(5)

where \( V \) = house prices
\( \bar{J}_i \) = journey costs
\( SC_i \) = social class of zone
\( PD_i \) = population density
\( GB_i \) = proximity to green belt.

We need to find a value for \( \gamma_i \) such that a unit change in \( \gamma_i \) would have the same effect on \( T_{ij} \) as a unit change in \( \bar{J}_i \). That value can be deduced from Wabe's equation, where we can derive trade-offs between journey costs and land use characteristics, holding house prices constant. We can see from this equation that to obtain transport equivalents of land use change we divide the land use elements of the equation by the coefficients of travel cost. Therefore:

\[
\gamma_i = \frac{c}{b} SC_i + \frac{g}{b} PD_i + \frac{h}{b} GB_i
\]

(6)

16. The attractiveness of any zone as a destination, at any rate when work trips are being considered, is clearly connected in some way with the job opportunities in that zone. If, for example, a zone has three kinds of employment each with a different wage rate, the attraction of that zone could be assessed in terms of the different wage rates, weighted by the share of each industry in total employment. In the same way as with origins, \( \alpha_j \) may be written:

\[
\alpha_j = \sum_k W_k \cdot O_{kj}
\]

where \( W_k \) = the wage rate for industry \( k \)
\( O_{kj} \) = the proportion of total employment in zone \( j \) generated by industry \( k \).

The meaning of footnote 1 will now be clearer. The utility function may be regarded as an aggregate of all utility functions. \( \gamma_i \) and \( \alpha_j \) represent the means of zonal
quality; different people have different distributions about those means. Each person selects the best \(ij\) pair for him, given the constraints, and this can give rise to an aggregate utility function of this general form if the distribution of \(\gamma_i\) and \(\alpha_j\) is assumed to be appropriate.

EVALUATION WITH A CONSTRAINED GRAVITY MODEL

17. So far the discussion has centred on an unconstrained distribution model. It has been shown that, given an unconstrained gravity model as in equation 2, equation 3 can be used to estimate the difference in surplus between two different land use plans. In diagram 2 the change in surplus would be measured by areas 4 through 10. But gravity models are not of this form; they are either singly or fully constrained. It is not possible to derive a utility function from the constrained models, since, as noted earlier, they are not, strictly speaking, demand functions. It is convenient, therefore, to make use of the surplus function derived in the unconstrained case.

18. If equation 3 were used as it stands, areas 4 through 10 would measure the change in surplus resulting in a fall in price from \(P_1\) to \(P_2\). However, if output \(T_1^*\) in diagram 2 is the constrained level of output, at price \(P_1\), the surplus is represented by areas 1 and 2. If there is a price change accompanied by a change in the level of constrained output, the surplus is then measured by areas 1 through 9. The actual change in surplus in the constrained case is therefore areas 3 through 9. A different method of measurement offers the solution to the problem of evaluation of surplus when constrained gravity models are being used. The surplus may be measured by assuming first that a shadow price, \(SP\), sufficient to achieve the constrained level in demand, is actually charged. In that case, the change in consumer surplus is

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Diagram 2
measured by areas 2, 3, 4, 5 and 6. The change in shadow price revenue is represented by \(-2, +7, 8, 9\). If these are added together, the result is areas 3 through 9, as before.

19. This last result suggests that in evaluating land use changes with a constrained gravity model a set of shadow prices$^2$ should be calculated that will give the same distribution with an unconstrained gravity model as would be achieved with a constrained model. The surplus function derived in paragraph 11 for the unconstrained case can then be used to evaluate surplus, but with the shadow prices added to the actual prices ($C_0$). When the surplus has been calculated in this fashion, the change in shadow price revenue may be added to arrive at user benefit. However, research results have indicated that a modification of the method currently used by the Department of the Environment to evaluate transport changes gives substantially the same result. Since this modification, known as Method II(L), is both easier computationally (especially in the case of a non-exponential gravity model) and more in line with current practice, it is this evaluation method that will be most fully discussed.

**Method II(L)**

20. Conventional transport appraisals calculate surplus by evaluating the following equation (the superscripts 1 and 2 refer to the plans being considered):

$$\Delta S = \frac{1}{2} \sum (T^1 - T^2)(C^1 - C^2)$$

(8)

In terms of diagram 2 this is represented by 4, 5, 6, 7, 8, 9, 10. Given that the Marshallian definition of consumer surplus can be regarded as the money value of "utility" minus expenditure, equation 8 can be rewritten as:

$$\Delta S = \frac{1}{2} \sum (T^1 - T^2)(C^1 + C^2) - \sum (T^2 C^1 - T^1 C^2)$$

(9)

The term $\frac{1}{2} (T^1 - T^2)(C^1 + C^2)$ is "utility". In diagram 2 it is represented by areas 6, 9, 10, 13 and 14, and $T^2 C^1 - T^1 C^2$ is represented by areas 13, 14 - (4, 6, 7, 8). The difference between the two is areas 4 through 10, which is the surplus as measured above. This result, as will be seen, is useful when one is considering constrained gravity models.

21. Method II(L) differs from the transport method in that the shadow prices derived above are added to the $C_0$ and the shadow price revenue change is added to the resulting formulae. Surplus can be viewed as "utility" minus expenditure. Since "shadow price revenue" is not actual expenditure it should be added to the traditional surplus formula. The benefit formula is then:

$$\Delta S = \sum \left\{ \frac{(T^1 - T^2)(C^1 + SP^1) - (C^2 + SP^2)}{2} + \sum (T^2 SP^2 - T^1 SP^1) \right\}$$

(10)

which, in the same way as equation 8 was rewritten, becomes

$$\Delta S = \sum \left\{ \frac{1}{2} (T^1 - T^2)(C^1 + SP^1 + C^2 + SP^2) - T^2 (C^1 + SP^1) + T^1 (C^2 + SP^2) \right\}$$

(11)

which is represented by areas 3 through 9 in diagram 2. In this form we assume that the qualities of that zone remain unaltered but the constraints are changed.

$^2$For a discussion of these see paragraph 22.
THE ECONOMIC APPRAISAL OF LAND-USE PLANS

H. Neuburger and J. Wilcox

22. A fully constrained gravity model (equation 12) will be used to demonstrate how, in the more general case where \( \gamma_i \), \( a_i \) and \( C_0 \) all change, the evaluation procedure works in practice:

\[
T_y = O_i a_i D_j b_j e^{-\lambda C_0}
\]

where

\[
a_i = \frac{1}{\Sigma b_j D_j e^{-\lambda C_0}}
\]

\[
b_j = \frac{1}{\Sigma a_i O_i e^{-\lambda C_0}}
\]

A \( \varphi \) is so defined that \( b_j D_j = e^{-\lambda \varphi} \) where \( \varphi_j = \sigma_j + \varphi_i \), and \( \psi_i \) is so defined that \( a_i O_i = e^{-\lambda \psi} \) where \( \psi_i = \rho_i + \gamma_i \) (the \( \gamma_i \) have been discussed earlier, and \( \rho_i \) and \( \sigma_j \) are the shadow prices). It is then possible to rewrite equation 12 as:

\[
T_y = e^{\lambda \varphi - \lambda \psi - \lambda \psi_0}
\]

and equation 11 \(^3\) (by substituting \( C_0^1 + \psi_i^1 + \varphi_i^j \) for \( C_0 \) in this general case) as:

\[
\Delta S = \Sigma \left( \frac{1}{2} (T_y^2 - T_0^2) (C_0^1 + C_i^2 + \psi_i^1 + \psi_i^2 + \psi_j^1 + \psi_j^2) \right.
\]

\[
- (T_y^2 C_y^2 - T_0^2 C_0y^2) + (O_i^1 \gamma_i^1 - O_i^2 \gamma_i^2)
\]

\[
+ (D_j^1 \sigma_j^1 - D_j^2 \sigma_j^2)
\]

This is represented by areas 3 to 9 in diagram 2. It will be observed that the first three terms refer only to transport accessibility, and the last two to "niceness". This means that it is possible to evaluate "niceness" and proximity independently. Once we have achieved a divorce between the land use and transport aspects of accessibility, it is no longer necessary to regard the \( O_i \)'s and \( D_j \)'s of equation 14 as trip ends. They can be regarded as population and employment. This means that we can avoid problems arising from land use evaluation being dependent on the responsiveness of travel to accessibility, and it will become less transport-based.

23. Thus, in order to evaluate a project using Method II(L), a fully constrained distribution model can be run in order to produce values for the \( T_y, \varphi_i \), and \( \psi_i \) of equation 13. The \( \gamma_i \) and \( \sigma_j \) can be estimated independently \(^4\) after the distribution model has been run, and the final terms of equation 14 can then be calculated.

24. The evaluation methods proposed here are for the purpose of comparative static consideration of two alternative land use configurations for the future. Very often, the kind of decision to be taken is whether to adopt some policy which involves moving population or employment which would otherwise have remained where it was. In this case there are two elements additional to the evaluation described above. One of these is the unpleasantness of disruption as a result of involuntary migration: on this we have nothing useful to contribute, although the principles are fairly clear. The second element is the transitory land use benefits and costs. Gravity models tend to represent equilibrium patterns of travel after most people have established themselves in their locations. Initially many people will continue to travel to their old jobs, shops, etc. In this case, accessibility changes may be valued under Method II in the way examined by Quarmby \(^2\) and others. If we are moving

\(^3\) It will be noted that the change in shadow price revenue cancels out.

\(^4\) See paragraphs 15 and 16.
certain people we designate them by a zone, and then their \((C_u)\) are modified by their new location. Their benefit is represented by:

\[
\Delta S = \sum_y T_y (C^1_y - C^2_y)
\]  

(15)

In time they will modify their patterns so that the benefits will be measurable in the long term in the way described above.

CONCLUSION

25. The aim of this paper has been to show how some of the methods used to evaluate transport changes may also be used in the evaluation of land use changes. It has been shown that, by using shadow prices, an operational method of evaluation can be derived, and also that a simpler linearisation is available.

REFERENCES


