Review of Studies Leading to Existing Values of Travel Time

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This paper attempts to emphasize the most empirical contributions to the valuation of travel time under varying circumstances. Most of these studies estimated these values as by-products of single or simultaneous travel choice and demand models in which the emphasis is on prediction rather than on capturing the concept of the notion of the value of travel time. Most of the studies discussed have produced total sample values of travel time savings due largely to the inadequate sample sizes required for stratifications and have resulted in insignificant income-related values. However, the values do tend to show some semblance of consistency when converted to international units, but before improved (stratified) empirical estimates can be made, improvements to the procedures previously used to obtain estimates are required.

This paper discusses the approaches adopted in recent empirical studies to estimate the value of travel time savings (VTTS) for work and nonwork circumstances. The three areas in which empirical research has been concentrated are work travel time, commuting time, and nonwork, noncommuting time.

VALUE OF WORK TRAVEL TIME

Work travel time encompasses travel by individuals as part of the work function. With few exceptions (2, 3, 4, 6, 9, 12, 16, 17), useful empirical evidence is absent. Most other useful studies are carefully reasoned expository arguments, based on the economic theory that employers will hire labor as long as its value to them is greater than its cost. Thus, at the margin, the wage rate is a useful measure of the value of production lost or gained by changes in the work force, providing that the labor adjustments are small relative to the markets in which the prices are set and that no changes result in wage levels.

Imperfections in the economy distort the appropriateness of the wage rate as a base measure; for example, continual exchange opportunities between income and time are confounded by minimum-wage, maximum-hours legislation. Empirical work, however, has not advanced sufficiently to provide a definite alternative. The behavioral studies (2, 3, 4, 6, 9) are the only attempt to provide an alternative measure of the value of work time, but with limited empirical success.

There appear to be well-defined areas of evidence: the macrochoice models used in the United States for the valuation of business-travel time savings for air passengers, the microchoice model used in the Italian Autostrada route choice study (2), the Sydney-Newcastle route choice study (54), and the case study (interview) and survey methodology undertaken in the United Kingdom to determine the marginal wage increment as part of the overall valuation of work travel time for road transport. This latter approach focused on a broader spectrum of occupational and income groups. In this paper, the U.S. and U.K. approaches will be reviewed separately.

Macrochoice Methodology

The consensus of opinion on the value of work travel time savings associated with air travel is that it varies from 2.5 times the average earnings rate (8) to the average earnings rate (1, 7, 10). The major objective of these studies was to improve the explanation of demand by introducing time as part of the price of travel rather than as a factor affecting tastes. However, two authors of research reports also made frequent reference to the theoretical and empirical estimation of the value of business air travel time. Using a trip distribution function on home interview data, Gronau (4, 5, 6) selected a value by maximizing the variation in the demand for trips between zonal pairs (in a single origin-multiple destination network). This is demonstrated by the explanatory variables when different arbitrary values for the income-time ratio, from 0 to 1, are used. De Vany (3) used aggregate data and inferred an indirect estimate of the value of time from the aggregate elasticity measure, i.e., the ratio of the percentage change in the time spent traveling to the percentage change in the price, when the price change is small.

From a number of alternative hypotheses on behavioral interaction, Gronau, in his initial research (4), describes the demand for trips between origin i and destination j in terms of the generalized cost of the trip (comparison of the price of the trip and the trip's elapsed time, weighted by the mean hourly earnings, designed as a direct estimation of the value of time as a percentage of the average wage rate k), the traveler's income, and the measures of origin and destination attractiveness. The function stems from Gronau's assumption that the value of time is necessarily assumed to be proportionate to the wage rate, since the iterative maximum likelihood procedure does not allow for a more complicated and perhaps more realistic assumption. Individuals with a higher income have a higher value of time and are more likely to use the faster mode. Since the comparative advantages of alternative available modes are related to the distance traveled, Gronau introduced distance into the generalized cost function for identification of the kinks in a time-price isoquant. For any given time-price relationship, the value of time k determines the kink at which the individual is located.

Gronau has thus identified the segmented market for business travel for time and cost trade-offs and has provided a distribution mechanism for valuing air travel time. In the initial research Gronau used simple regression (4). Considering all business trips, he estimated an implied income-time ratio k of 0.40 from an equation for which r^2 for the whole equation was statistically significantly greater than the r^2 for other equations. This work, however, emphasized the effect of travel time on the demand for travel and did not estimate the value of time. In a later study (6), which looked at professional occupations only (78 percent of the sample), an alternative method was introduced. The dependent variable was changed to represent the probability of travel to a given destination j within a given income group i. All trips originated in New York. Weighted regression was used on cell means (destination by income). The empirical estimate of the value of domestic business air travel time derived from more efficient estimates was approximately equal to the average wage rate. Given the structure of the travel market, the latter result appears more realistic, assuming that a high positive correlation between the value of time and the wage rate does not indicate that a homogeneous constant exists for any proportion of the population. This is substantiated by only marginal differences in the values of r^2 in the estimating equations (6, Table 7) and the totally different result in the earlier study.

Gronau suggests that VTTS is essentially an empirical matter on which the only guidance given by theory is that it is positively related to the wage rate. Whereas Gronau used a single origin data set that included the income of each traveler, De Vany did not have access to such data for city pairs and had to face the problem of using zonal income data. De Vany related the number of annual business air passenger trips between city pairs to the fare per kilometer for a trip between i and j, the travel time per kilometer, the distance between cities, the populations of the respective cities, and their mean zonal income.

Distance was introduced as a price and time elasticity determinant on the grounds that the ratio of price to trip time varies systematically with distance and that the theory indicates that, as the ratio p/wt changes, where w is the wage rate, price and time elasticities change. Note the similarity to Gronau's assumption. Although Gronau used one of the few data sets that gave the income of each traveler, De Vany noted that most intercity studies usually create difficulties in identifying income levels and the average wage rate. Apart from this inconsistent evidence about the assumption that wage rate differentials are due to intercity heterogeneity (although cities are too alike for income variance to show), De Vany recognized the general deficiency and adopted an alternative procedure of calculating the value that travelers must have placed on their time to have produced the estimated time and price elasticities.

The distance variable was included to convert travel time and price from rates per kilometer to total time and cost. If distance is maintained as a constant, the effect of fare and time changes on routes of differing lengths can be compared. If we use the theoretical relationship that

$$(\partial T/\partial t) = w(\partial T/\partial p) \quad (1)$$

and require that the consumer's response to time changes be tied to his or her responses to price changes through the value of time, then multiplication by pt/T_{ij}, where T_{ij} is the number of annual passenger trips between city i and city j, gives

$$we_p t = e_t p \quad \text{or} \quad w = (e_t p)/(e_p t) \quad (2)$$

the standard point elasticity of demand definition. At mean trip lengths of 1046 km (650 miles), with e_t = -0.47 and e_p = -1.08, the value of air travel time in 1968 was $7.54/hour. De Vany suggests that this value approximates the average wage rate. This lends support to later findings of Gronau but disagrees with his earlier finding that, for intercity travel, time is a considerably less important determinant than standard theory might indicate. The use of an average elasticity measure (related to the assumption of constant elasticity), however, is likely to conceal more than it reveals, especially if the time difference is a composite of the various heterogeneous components of travel time (i.e., walking, waiting, transferring, and in-vehicle time).

These macromodels have some questionable features.

1. Given that the elasticities of price and time are acceptable in magnitude and sign, a prediction of the demand for future modes would require the assumption that elasticities are stable over time. As a short-run model, Gronau's assumption appears to be realistic that price and time for air travel do not react to any changes in the demand for trips because of their administered nature (set by government agencies). In addition to these fixed (relative) prices, any change is difficult to measure in the short run. With this constraint, the whole question of the inadequacy or irrelevance of the elasticity approach for short-run valuation of air travel time is raised. Based on this objection, land-mode situations seem more suited to elasticity interpretation. Time-series data are required for an investigation of elasticity changes over time.

2. In addition to the stability of elasticities per se over time, a compounded potential instability seems to be due to the initial aggregation of the data set, i.e., using mean zone estimates for price and time, particularly for excess trip times, connecting mode costs, and income in the case of De Vany. Such an approach introduces all the associated features such as ecological correlation and the possibility of intrazone variance exceeding interzone variance. Ecological correlation occurs when the coefficients of correlation are computed on the basis of measures applying to territorial or zonal groupings as a whole in contrast to correlations between the cases contained within the groupings.

3. Both studies, by considering one time variable, implicitly assume equal importance for all components of travel time (waiting, walking, transferring, and in-vehicle time). This criticism is directed to travel up to 322 km (200 miles), for which the overall trip by bus can often have a comparative time advantage over the air trip because of the delays involved in access and egress in air travel. Gronau suggests that air travel is an effective competitor only for trips in excess of 217 km (135 miles).

4. The elasticity measure is defined in terms of small price changes. When the price changes between

modes are large, then an alternative elasticity measure appears more appropriate, unless the Gronau and De Vany assumption of constant elasticity over the entire range is made. Whenever two time-price situations lie along a curve of constant point elasticity, the arc elasticity will be the appropriate measure and equal to that constant value, regardless of the size of the step.

5. The value to the employer of work travel time savings, which might include any reductions in disutility to the employee, must consider for a given level of production the direct and indirect savings in labor costs due to travel time savings. In addition, the distribution of travel time between the employee's and the employer's time could make a considerable difference in the deviation of a final value of time from the wage rate (15). When consideration is given to such an influence, the value of time is likely to be less than the average wage rate.

6. Some potential confusion could arise through the use of the two phrases price of time and value of time. The consensus of opinion leads to the following definitions: The value of time is the amount of money an individual is willing to pay to save a unit of travel time; the price of time is the amount of money an individual has to pay to save a unit of travel time. Gronau emphasizes the price of time, although the inconsistency associated with interchanging the words price and value can be confusing. Although one could argue that the price of time can equal the value of time in a constrained financial context, the presence of imperfections and distortions leads to disequilibrium where there is a divergence between the market rate of exchange and the marginal rate of technical substitution. Hence the price of time does not equal the value of time. Gronau's conclusions are only correct if a position of equilibrium is assumed. This is empirically unlikely. Although he refers generally to the price of time, perhaps on some occasions he should be referring to the value of time.

Both authors appear to recognize the associated marginal wage increments; however, no allowance is given for this. This might be explained by the multiple-purpose journey data set and apparent desire to use the same model for all journey purposes, a give-and-take compromise approach, without considering the heterogeneous structure of the choice process involved under differing circumstances (26). This same criticism applies to the Italian Autostrada route choice study (2). Such an implicit stand prejudges the suitability of such an approach for work trips, but is quite acceptable for commuter and leisure trips (ignoring at this stage the relative merits of the disaggregate, probabilistic, behavioral models).

Production Cost Approach and Nonwage Overheads

Although U.S. air travel studies have emphasized procedures that show promise in estimating a behavioral value of time (i.e., for prediction), they make no contribution to the calculation of resource values of time required in evaluation. The empirical method used in the United Kingdom appears to provide a more promising mechanism. Within it, all resource costs can be considered that are associated with employment of labor as a factor of production that undertakes travel on behalf of the employer. This section looks briefly at the procedure adopted for assigning a meaningful markup on the wage rate to allow for other costs of hiring labor. These other costs are elements [referred to as the marginal wage increment (MWI)] that are saved if the labor-time input ratio is reduced while production remains constant. Travel time saved by employees in the course of their work can be regarded as a change in productive time and hence, if production remains constant, both direct and indirect savings in labor costs will result. In the absence of direct evidence, a markup of 10 percent was applied to the gross wage rate, including income-related payments. Three studies have been completed in the United Kingdom (12, 16, 17), each study being essentially exploratory because of the absence of prior guidelines.

The initial study (12) was designed to review existing British evidence on the effect of road improvements on the MWI and used a technique of personal interview with a senior official of the larger companies representative of their industries. The study indicated an absence of substantive evidence and a general unwillingness to accept that there could be any material and quantifiable changes in overhead due to road improvements. Under pressured, biased interviewing, two respondents estimated savings in overhead from a fraction of 1 to 3 percent and a third estimated under 5 percent. Other respondents were reluctant to concede any saving at all in overhead (12, p. 2).

A major criticism of this approach, apart from the "guesstimation" potential, is the difficulty, over time, of separating the unique impact of the road improvement from those technological and institutional factors (e.g., speed limit) external to the firm and the firm's maintenance trade-off adjustments. Respondents would be acting in a rational manner by refusing to give an estimate of overhead changes due to a specific improvement. In response to the issues raised in this initial pilot study, two other studies were undertaken.

One of these studies (16) investigated 165 firms in the consumer goods industry for which transport was an important ancillary activity. The short-term MWI was found to include meal allowances, overnight expenses, special clothing and uniforms, samples, literature and tools, and welfare benefits (e.g., pensions). The percentage markup of such costs on salary suggested an MWI of about 20 percent, double the previous 10 percent. The single most contributory expense over all person categories considered (salesmen, transport drivers, and service engineers) was overnight expenses. This approach to estimating the short-term MWI offers a more causally meaningful procedure than the alternatives suggested, despite limitations of sampling error and the difficulty of deciding on the assignment of costs attributable to marginal employee or other factors.

The most recent study (17) selected 17 firms that had large distribution networks to assess the longer term savings resulting from reorganization of distribution and administrative charges that include overhead. Detailed information on costs related to constant output and on costs related to a particular site was obtained from food and allied industries. The main finding indicated an unclear relationship between the average long-term cost saving per driver because a decision to reduce the number of depots generally produces a restructuring of investment outlay, and this changes the composition of the MWI (17, p. 8). The only possible conclusion was that the long-term MWI must be larger than the short-term MWI; otherwise, the investment would not take place.

The research team of the Commission of the Third London Airport, using the above findings, raised the wage rate 50 percent to obtain a value time of business air travelers. It was argued that overhead costs and income-related payments of business air travelers are higher than those of business travelers in general. However, Dooley and Young went a step farther and investigated the categories of overhead costs themselves. They recommended a markup of 200 percent for overhead.

Again the use of one single percentage markup is subject to doubt. Research is required to investigate not only the components of overhead and other costs but also the incidence and magnitude of such costs for industries that are significantly involved in either air or land travel. Such a study for air travel has recently been completed in Australia (15). The total resource costs incurred by the employee, the employer, and the community as a result of an employee's undertaking business air travel were considered. The resource values of time savings for both domestic and international business travel were found to be less than the average wage rate for each of the six outward and return trip stages. This is in contrast to the 150 percent of the average wage rate suggested by the Commission on the Third London Airport. A behavioral value of time for the outward access portion of a business domestic air trip was also estimated in the context of a choice between various private and public land modes and was found to be greater than the resource value but less than the average wage rate. The detailed values are not yet available for quotation. A number of comments can be made about this approach.

1. Speculation on long-term savings attributable to a particular site is usually unreliable, unless recent reorganization has occurred.
2. Survey or interview methods suffer from the miscomprehension of the respondent (and often the interviewer) about overhead costs as defined in terms of the MWI. This produces undesirable ramifications when firms interpret overhead in the cost accounting sense.
3. In the long run, regional diversification and the decision on choice of depots can spread the distribution costs over a wider region. A trade-off between these regional costs with the reduced costs of fewer depots must be considered to determine the directional change of the MWI.
4. No way has been found to assess whether the overhead costs that make up the MWI would in fact be saved by reducing traveling time of employees (14, p. 67).
5. Traffic densities are an important determinant of stability of the MWI. When traffic densities are lower and roads are improved, the chance is less that newly generated traffic will cancel the advantages of any original savings in overhead. Hence, regional diversification and traffic density must both be considered in any long-term assessment of the MWI. Fullerton and Cooper (12) did give evidence to suggest that, for short-range urban travel, increasing traffic density over the slow rate of road improvement countervailed any potential savings in overhead attributable to road improvements. Given that approximately 35 percent of working time appears to be a fairly typical proportion of time spent traveling (17, p. A4) and that 50 percent of journey distance is under 80 km (50 miles) (16, p. 4), the assertion of countervailing reaction might be justified.
6. With the exception of the Australian air study by Hensher (15), the above approach ignores any change in utility to the employee as a result of a travel improvement, i.e., the disutility of the travel experience itself.

This discussion on the production-cost approach has shown that little research into the value of work travel time has been undertaken. The 10 percent MWI traditionally used in the United Kingdom for land-mode activities and the 50 percent MWI used for air travel must be placed in doubt, especially as an average long-term MWI. The paucity of empirical evidence from all procedures adopted only serves to emphasize that the value of work travel time is at least equal to the average wage rate for nonair travel and is less than the average wage rate for air travel.

VALUE OF COMMUTING TIME

Haney (23) conducted a survey about VTTS that indicated that existing values of travel time in the United States were largely based on intuition and nonbehavioral engineering estimates and lacked reliable theoretical content. The most common approaches emphasized a valuation based on operating costs or tolls. In the United Kingdom, the Victoria Line rail study prompted a detailed look at the VTTS. Before that, most values were suggestions, assumed values, or derivations from car operating cost models, and not much consideration was given to the perceptual process inherent in individual value.

Since 1965, a number of important studies have been completed that estimate VTTS by studying the apparent trade-off between time and cost by travelers who have a choice of mode or route (6, 18, 19, 20, 21, 22, 24, 25, 26, 27, 29, 30, 31, 32, 36, 37, 38, 40, 41, 42, 43, 44, 50, 52, 53, 58, 59, 61, 64, 65). These studies are by no means unequivocal, but because of the compelling need to evaluate time savings in transport projects, certain broad, generally accepted principles have emerged. Three basic approaches have been adopted: revealed behavior approach, willingness-to-pay approach, and housing prices approach.

Revealed Behavior Approach

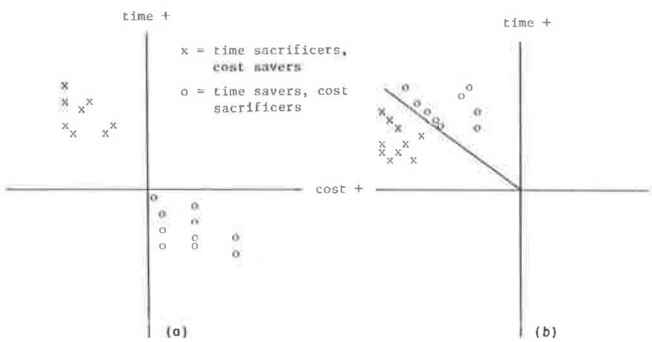
The fixed origin-destination journey to and from work is a unique pattern of movement, amenable to sophisticated statistical techniques. Because of the habitual nature of such a trip, information on the revealed behavior of an individual faced with available alternative routes or modes is relatively easy to acquire and relatively more reliable than data on variable-destination trips. For this and other reasons, a disproportionate empirical emphasis has been placed on the study of the explanation of commuter trips and valuation of commuter travel time savings. With few exceptions (19, 26, 38, 40, 41, 52), the values of travel time have been a secondary output of these studies.

The key empirical assumptions underlying the stochastic disaggregate models used are as follows:

1. A real choice exists;
2. For studies in which automobile travel is an alternative, the individual must hold a current driver's license and have an automobile available for the journey to work; and
3. Sufficient variance must exist in the distribution of the modal and trip characteristics to enable a meaningful estimation of VTTS.

The time-cost trade-off concept for commuters was developed by Beesley (20), in a unimodal context, to derive an implied value of travel time by comparing travelers who choose a time savings at extra cost with travelers who choose a cost saving at extra time (Figure 1a). Commuters' behavior is revealed by their trade-off between time and cost in an attempt to save time or cost. Figure 1b shows superimposition of the two categories of traders. The linear function drawn from the origin to divide the groups is representative of some bound of minimum misclassification or minimization of bad choices, i.e., those commuters who, by choosing the alternative mode, could have either saved time by paying less money than the value of time implied by the slope of the line or saved money at the expense of a

Figure 1. Two categories of commuters.



smaller time increase than the value of time implied.

This study provided a conceptual framework for all subsequent studies based on revealed behavior. This trade-off procedure has been the most useful for the empirical estimation of VTTS. However, Beesley's study suffered from a number of inadequacies, e.g., a biased small sample, a line of minimum misclassification emanating from the origin that implied equality between the average and the marginal value of travel time, and a consideration of time as a homogeneous entity.

More refined statistical techniques have subsequently been used, particularly discriminant analysis, probit analysis, and logit analysis. Discriminant analysis became popular in the United Kingdom because of its classification properties and its use in Quarmby's study (32). However, this statistical tool has recently been criticized as an effective mechanism for explaining modal choice and, hence, the value of time (26, 53, 58). A main criticism has been the assumption of knowledge of a priori probabilities, where variation in spatiotemporal stability makes interpretation of such probabilities difficult. In the studies using discriminant analysis, the unrealistic assumption of equal a priori probabilities of each group (the Bayesian hypothesis) or the assumption of equality of the ratio of a priori probabilities to the ratio of the group sizes is adopted.

Quarmby (32) provided the first attempt to unravel the argument between perceptual and manufactured measuring procedures for the two key determinants of the VTTS. Using the criterion that valuation should reflect the behavioral interpretation of a situation as seen by the individual, Quarmby recommended the perceptual process with certain important modifications. Believing that unedited, reported, and perceived data contained a high degree of error not indicative of the individual's true perception of a situation, Quarmby used a behaviorally perceived measurement process, expressed in terms of car-kilometer cost, that maximized the explanatory power of the discriminant function. The car-kilometer cost was selected as the sensitive parameter on the grounds that it is more open to misperception and guesstimation than any other component of the time or cost of travel. In addition to the incorrectly perceived costs, however, there appears to be a genuine variance in opportunity costs. For this reason, Beesley (19, 20) recommends deriving estimates of VTTS from public transport choices. Although this stand avoids the issue of car costs, it also eliminates a major circumstance under which such a value can exist. The other components were perceptual.

The research by Lisco (30) in the United States; by Quarmby (32), Rogers, Townsend, and Metcalf (34), and Watson (53) in the United Kingdom; and by Hensher (26) in Australia has provided sufficient evidence to suggest that individuals are able to provide sufficiently reliable information on the perceived times and costs of their usual means of travel, except for car costs. However, over all individuals, a sufficiently reliable global average car cost can be obtained. Reliability is interpreted in terms of the deviation of the reported perceived costs from the true values compared with the deviation of the manufactured values from the true values. For the alternative mode, however, the agreement is not so evident. Because of the habitual nature of the journey to work, reported information on the alternative mode tends to be biased against the alternative. For example, Quarmby found that car users compared with bus users tend to overestimate the times of bus travel by about 10 percent. One argument used to substantiate this state of affairs is that it is a means of rationalizing the individual's present mode choice.

Two studies (24, 26) have independently adopted a procedure for valuing the times and costs of the alternative mode, based on the criterion that the perceived values placed on a usual mode represent the best estimates of the values associated with this mode by the individual who currently travels by another mode and sees this mode as an alternative. If the individual was required to use the alternative mode, his or her evaluation process would conform with that of present users of the alternative mode. The resulting values of travel time appear to conform to other values, derived independently.

In the research of Hensher and Merlin and Barbier, the estimated value of waiting time is higher than that for walking and transfer time; in the work of Rogers, Townsend, and Metcalf, the opposite generally exists. If there is a disproportionate amount of walking and transferring in the British transport situation, then the latter relationship might be justified. The safest conclusion is that one is unable to compare directly results from different countries and different towns within a country and under different circumstances. Hensher (21, 23) found that the VTTS based on the overall travel time differences did not equal the weighted mean VTTS based on the linear addition of the heterogeneous components of time differences.

Stopher (36) also contributed to the debate on empirical valuation in the United Kingdom. His basic methodology was similar to other studies mentioned. The main difference was that Stopher initially divided his sample of London commuters into groups, each group corresponding to a certain time difference and cost difference bracket. He then measured the proportion using one mode in each group and treated this as the probability of using that mode for these time and cost conditions. This is a type of stratification process. For each of a range of values of time λ, a linear regression of probability of choosing the car, on the individual values of $[(c_1 - c_2) + \lambda(t_1 - t_2)]$, was conducted. The value of λ giving the largest correlation coefficient was chosen. The main criticisms of his study are the implicit assumption of homogeneous disutility of travel time, which in effect biased upward the value of in-vehicle travel time, and the initial use of a linear estimation procedure for an S-shaped behavioral relationship. Stopher subsequently reanalyzed his data by using the logit transformation (37).

Other U.K. studies (18, 59) used new data sets and existing techniques, and other studies confirm that the U.K. value of commuter travel time tends toward 25 percent of the average wage rate.

Although discriminant analysis gained a degree of respect in the United Kingdom, the improved techniques of probit and logit, designed specifically to handle a binary dependent variable (choice of mode), were becoming more popular in the United States. Lisco (30) and Lave

(29) derived values of time from the probit model (the cumulative normal probability function) by using existing and somewhat inadequate data.

Lisco is the main defender of manufactured measures of time and cost. He takes the stand that assumptions are not necessarily important provided that the model predicts satisfactorily. Hence, perceived data are inappropriate, since manufactured information gives as good an explanation of behavior. Although this might apply to Lisco's findings, Thomas (38) and Quarmby (32) indicate that their perceived data gave a much smaller percentage of misclassified choices than the manufactured data.

Limited sensitivity testing, however, did prevent Lisco from asserting any stability conditions on each measurement procedure. The opposite was the case for Quarmby and Thomas, who conducted extensive sensitivity testing on the model. Lisco's study (30) is one of a few (24, 34, 38) to consider the standard errors associated with a mean value of travel time derived from the ratio of the time and cost coefficients. Although the statistical significance of the separate coefficients might be acceptable, the statistical significance of the ratio might be implausible. Apart from the internal structure of the variables and the limited sample of pure traders (159), Lisco better explains and estimates the value of commuter time. Pure traders in this context refers to travelers who face a trade-off situation between a quicker, more expensive mode and a slower, less expensive mode.

Lave's research (29) is conceptually similar to Lisco's work (30). His major contribution is the direct estimation of the VTTS as a percentage of the average wage rate. This is determined by weighting the relative travel time by the average wage rate and a random variable k whose value depends on the individual's preference for more work time income versus more leisure time. If the commuter prefers more leisure and less work, k is greater than 1.0; if the commuter prefers more work and less leisure, k is less than 1.0. Gronau's model (4, 5, 6) also gives a direct estimate of k; the VTTS is slightly lower than that of Lisco. Like Lisco, Lave devotes a considerable amount of time to careful examination of the internal and external structure of variables to ensure that the best behavioral specifications are used. It was unfortunate that the data were poor and, thus, negated the impact of some of the precise model formulation.

Hansen's research (24) evolved from a need to explain how people choose their means of transport under special conditions, e.g., various levels of car density and varying distances from Oslo. Unlike the other studies, the zonal requirement is introduced, but in a way that enables mode and trip characteristics to be initial behavioral measures based on individual behavior. Hansen found from a sample biased toward the higher income groups, older persons, and high car densities that, for the healthy Norwegians who "do enjoy walking" (24, p. 25), a marginal reduction in travel time is valued four times higher for a reduction in in-vehicle travel time than for a reduction in walking and waiting times. This opposite finding from that in the United Kingdom and the United States might be explained by the tight housing market in the Oslo area and the housing cost structure, which tend to push up the value of in-vehicle travel time in relation to areas where there is a properly functioning housing market.

The Hansen study seems to indicate that it is difficult to suggest that the VTTS can be generalized within a country, let alone between countries. Given the similarity in physical and socioeconomic characteristics among certain communities in different countries, the VTTS for certain groups in different countries might be closer (as a percentage of the wage rate) than that among groups within one country.

Thomas (38) offers the only important route choice contribution in the area of revealed commuter behavior [the Dawson and Everall study (2) followed similar lines]. Using the time-cost trade-off approach for the individual facing a choice between a tolled and a nontolled route, the study considered the sensitivity of the value of time to differing internal structures of the relative time variable. Cost differences were calculated directly from the toll rate, and no consideration was given to any differences in in-vehicle trip costs. The outcome of the discriminant function (with a logit transformation) indicated a market difference between the value of time based on the perceptual measures ($3.82) and that based on manufactured measures ($1.82). Values were estimated for reasonably small differences in the two sets of time measures. A mean of $2.82 was recommended because "an analysis of errors and biases in the motorist-perceived and test vehicle data shows that the true value of time lies somewhere between the two midpoint values" (38, p. vii). Even though the true value could be expected to be within the bounds of the two estimated values, the sensitivity of this model depends almost exclusively on the assignment of a journey time. In general, there is limited scope outside the United States to use techniques of route choice, time-cost, and trade-off, and the situations that do exist usually provide too little variation in the variables for reliable parameter estimation.

Thomas (38) concluded that time savings were income elastic. In an attempt to unravel a relationship among income, the amount of time saved, and the value of time, Thomas and Thompson (52) collected a new set of route choice data. Using the same procedure, they tested a number of polynomial variable structures to relate the value of time directly to income. The only significant relationship of major dependence for the reported perceived data was value of time = $b_0 + b_1$(income). Although the model satisfied significance tests and standard error requirements, the high intercorrelation between straight time differences and income-adjusted time differences places some reservations on the actual VTTS estimated as a function of income. This direct method also assumes that the impact is the same for all states of the modal variables. Hence, any increase in income proportionally increases the VTTS without any consideration of possible structural changes of the modal variables.

Stratification of the large data set into three ranges of amount of time saved was adopted to estimate a different value of time for each range of time saved. The direct functional relationship between income and the value of time was maintained:

$$f(x) = a_0 + a_1(\text{toll}) + [b_0 + b_1(\text{income})](\text{time difference}) \qquad (3)$$

Stratification is preferred to the direct method because it avoids any double inference stemming from the ex post inclusion of a variable (e.g., income), which is also an ex ante perceptual influence on the internal structure of relative times and relative costs. The inclusion of income as a higher order term gave a poor statistical fit. The final model dropped this direct functional relationship and used time differences between routes as the only route variable for which commuters perceived a benefit and would be willing to pay.

Thomas and Thompson (52) have shown the difficulties in using higher order terms and the problem of generating a table of values of time over various ranges of income and amounts of time saved. It appears that such an approach expects too much from the data. The failure to allow for the relationship between trip length and the amount of time saved makes the usefulness of stratification questionable. The main contribution seems to be the support for the assertion that the VTTS is a direct function of income.

In general, most studies emphasize the estimation of a unique VTTS with little satisfactory consideration of the variations in the value with respect to income, trip length, and amount of time saved. A word of warning is given to the planner who might use the unique values in an economic evaluation model: He or she should be informed of the large variations observed in the few studies with data that are capable of eliciting such variations. A unique value could be as misleading as no value.

Willingness-to-Pay Approach

Lee and Dalvi (40, 41) use the notion of a diversion price to determine the VTTS for each individual, at the point of modal indifference, with respect to total travel time and travel cost. The diversion price is the increase in travel cost on the preferred mode that would make the individual indifferent about modes.

Variations in VTTS were calculated by separately analyzing commuters who travel by a faster, more expensive mode (minimum set) and commuters who travel by a slower, less expensive mode (maximum set). These variations were related by regression to various factors, such as journey length, walking and waiting time, income, and age. The initial study (41), involving choices between public transport modes, concluded that time savers (cost sacrificers) apparently value time savings three times as much as the time losers (cost savers) but warns that the value of time is the product of the situation in which it is determined. The later study (40), using data on choices involving car use, found the VTTS to be higher for the car than for public transport but quite consistent with findings elsewhere. The mean values within the minimum set greatly exceed those within the maximum set. A comparison of the mean diversion price time values with the average value that best discriminates between car and public transport users (based on discriminant analysis) was considerably consistent (40, p. 200).

This novel approach has been criticized for using a diversion price obtained from a statement of intended consumer behavior, a hypothetical situation. Although the criticism is fair, it can be argued that the error associated with the diversion price approach (potential behavior) might be no greater than the error commonly associated with the derivation of a value of time from revealed actual behavior models as a quotient of two coefficients. A testable hypothesis is that, under habitual conditions commonly associated with commuter travel, the error associated with measurement of the times and costs of the alternative mode is high because the individual's revealed habitual behavior does not include the alternative mode in the choice process. Only when a change in time or cost actually occurs (or is predicted) do the alternative mode attributes appear to be actively considered. It has also been indicated that scanning is neither a continual nor a frequent process for most people. If people have not had recent experiences with the alternatives, their preferences will tend to be biased. However, if we have a diversion price that is related to alternatives, then no matter how the alternative is perceived, the interpretation will be conceptually valid.

Housing Price Approach

Wabe (42) attempted to value travel time by using a linear model concerned with the influence of demand (at a microlevel) on the determination of individual house prices during the first 3 months of 1968 for the London metropolitan region. Becker (44) and Mohring (43) also looked at the trade-off between lower house costs and lower travel costs in the United States.

In the Wabe model, a decrease of 1 new pence (p) in the cost of the journey to Central London was associated with an increase of £18.74 in the level of house prices. Similarly, a 1-min reduction in journey time to the center is reflected in house prices to be worth £20.38. The ratio of time and price coefficients indicates that 1 min is being valued at 1.0875 p or 65.25 p/h. This is quite similar to the 61-p car value of time estimated by Lee and Dalvi. An implicit assumption of Wabe's model is that, over large numbers, behavior is continuous, i.e., there is a gradual transition from one position to another (a trend from inner to outer areas). Problems of multicollinearity and crude specification of some of the variables reduce the reliability of this result, despite its consistency with other studies. Whereas the behavioral models discussed provide a trade-off mechanism between modes for a fixed residential location, Wabe is extending the consideration of valuation to include variable residential locations.

A potential criticism of this approach is the extent to which transport decisions are functionally ex ante or ex post to locational decisions, with respect to both residence and employment location. If the transport decision (i.e., mode choice) is a residual process, then is a derivation from residential-employment location trade-off necessarily indicative of the individual's value of travel time savings? Even if the transport mode decision is residual, there is no reason why consistent values of time should not be revealed by location choice and mode choice studies. Biases may be introduced into mode choice studies if the residential location decision is neglected. Wabe's approach appears to be a useful alternative for understanding the valuation of travel time savings (for a constant time difference between existing modes), in a somewhat more realistic context. Despite the doubts, this is the only study to have considered the relationship between transport and location decisions at the level of the individual traveler and to have made allowances for environmental and amenity circumstances.

VALUE OF NONWORK, NONCOMMUTING TRAVEL TIME

The purposes and nature of nonwork, noncommuter trips are more diverse than the limited number of techniques adopted to specify models capable of generating empirical estimates of the VTTS. Existing empirical studies fall into two basic categories: trip distribution models (46, 49, 50, 51) and mode (or route) choice models structured along the lines of commuter studies (2, 27, 52, 53).

Trip Distribution Function

The trip distribution function is a useful mechanism for relating the number of trips between any two areas within a network to the inherent characteristics of those areas and to a behavioral generalized cost function (BGCF) that explains why the expected number of trips between the areas should diminish as they become geographically more remote from each other. The VTTS can be inferred from the BGCF, which includes combinations of money price and journey times facing the would-be traveler between two areas. Most of these studies were primarily concerned with estimating the value of recreational services.

Data and model specification limitations have resulted in the restriction of empirical studies to situations involving trips from origin i to a single destination J. A typical distribution function is

$$T_{ij} = kO_i e^{-\lambda f(c_{ij})} \quad (4)$$

where

T_{iJ} = demand for trips,
k = trips to other zones, and
c_{iJ} = generalized behavioral cost.

In all the empirical studies, substitutability between trips to zone J and trips to other zones k is assumed to be trivial.

The general absence of information on money costs of travel on an individual basis has resulted in the inclusion of distance (kilometers) as a mechanism for relating time and cost. This intervening approach is most appropriate for recreation trips where there is evidence to suggest a high degree of multicollinearity between time and cost for unique destination-based trips. Colenutt (46) found r to vary between 0.966 and 0.989. The approach adopted by Smith, Mansfield, and Colenutt involved directly estimating the collinearity between journey cost and journey time by including in the behavioral cost equation only those parts of time differences unexplained by the relation between distance and journey time. The empirical requirements for such an approach are as follows:

1. The recreation area is homogeneous; i.e., it is attracting a single trip purpose (to a point destination). The test of homogeneity would be whether travelers to these destinations possess different attitudes about travel. This assumption is required to avoid the simultaneous equation bias associated with discarding the normal trip generation assumption that the number of trips is a function of all the opportunities in the transport sector and competing opportunities elsewhere.
2. A trade-off situation exists. This assumption requires the existence of distinguishable route speeds in the road network and a distribution of route choices so that travelers can take advantage of route choices by trading off time and cost. This also helps to reduce the collinearity between time and cost. This implies a nonlinearity between time and distance; otherwise, the pattern of individual responses to the distinguishable trip times will reflect random factors and not the value placed on time.
3. Travelers are aware of the route choices implied by the trade-off; i.e., choices are neither strongly independent of time nor random.

The exposition by Smith is the most concise. Smith (51) selected a sample to include all individuals who do and do not use a particular recreational facility (for trout fishing). An objective was to compare areas that were equidistant from the facility but that differ with respect to the alternative route facilities available and to the time taken to reach the recreation site. Multicollinearity between time and distance was avoided by use of an indirect method to estimate the impact on trip rates of a unit change in time. The procedure was as follows:

1. Estimate the general relationship between the time taken and distance traveled;
2. Based on the estimate, calculate an expected time for any distance and thus for an aggregation of zones; and
3. Introduce a variable, the deviation from the expected time to the time actually taken for the journey to the facility for each aggregation of zones.

Smith, using manufactured time estimates, calculated a VTTS of 50 p/h. One probable explanation of this high value compared with Mansfield's value of 13 p/h is the nonfulfillment of one of the basic assumptions of the trip distribution function, namely, that behavioral costs are independent of the demand for trips. Trout fishers may be more sensitive to an increase in time caused by having to travel on a longer route free of delays. In both studies by Mansfield and Colenutt, the trips from any zone were not numerous enough to affect traffic congestion significantly on any road that the zone residents use in common with those travelers from other zones.

The empirical results of Smith's study are generally inconclusive (51, p. 99). The main difficulty arose when an attempt was made to estimate empirically the coefficient of money cost. In many cases the influence of time was so strong that the calculated cost coefficient was apparently positive. In only two equations was the cost coefficient negative (from which the value of 50 p/h was calculated). Mansfield and Colenutt avoided this issue by using a variant on Smith's basic model. Mansfield defined the second variable in Smith's initial equation as the nonlinear piece of the time-distance relationship expressed as the difference between the actual and calculated journey time for a zone and called it "excess time." When speed variations exist, it is possible to describe journey times per kilometer from particular zones as higher than or below average for the complete sample. In the initial equation, distance includes the basic effect of journey time as well as vehicle operating cost. Using a function relating journey time to distance ($t = b_0 + b_1 d$), Mansfield and Colenutt obtain the marginal time element in distance. Hence the effect of a 1-min change in excess time becomes $(a_2/a_1) \times (C + b_1 t)$, where $(C + b_1 t)$ is the total cost per kilometer of the journey. It takes b_1 min to travel a marginal kilometer. The solution of the equation, for a selected car-kilometer cost, will produce an estimate of the value of travel time.

Colenutt (46, p. 184) gave values from which he concluded that "a strong case has been presented for considering the time values . . . to be spurious." He attributes this to the data.

1. Trip population is composed mainly of short-distance travelers [62 percent of trips were less than 64 km (40 miles)], who may not be so sensitive to small changes in travel time as long-distance travelers are.
2. Relative uniformity of the road network around the area may have obscured the time-saving behavior of some of the travelers. The motorways available do not offer any special travel time privilege to any particular market area. Hence, there is a close association between time and distance throughout the road network.

This discussion has served to illustrate the general direction in which the limited amount of research into nonwork, noncommuter time valuation using the trip distribution function is heading. Although many studies (2, 21, 27, 45, 46, 47, 48, 50, 51, 53, 55, 59, 66) have been calculated for such travel time values that confirm the tendency for recreation trip time savings to be valued less than commuting travel time, the limited evidence is somewhat diverse. So that the findings of most of these recreation studies can be understood, estimations of recreational values require much assistance from independent estimates of time values. This only serves to emphasize the difficulties of valuing such time savings under so many varied circumstances. Leisure trips may be useful in themselves and as inputs to other activities.

Mode and Route Choice Studies

Watson's medium range intercity mode choice study (53), Thomas and Thompson's route choice study (52), and Hensher's interurban choice of route study (54) provide the most reliable attempts to value nonwork, noncommuter travel time. Other studies, although estimating time values, have not contributed to the methodology but have applied well-tested techniques in the valuation of commuter travel time to other journey purposes.

Watson used the basic methodology of revealed behavior to study the importance of time and cost elements in determining the choice of mode in the Edinburgh-Glasgow corridor. The main data set emphasized social-recreational trips. From 12 models, the most satisfactory was as follows:

$$\text{Choice of mode} = a_0 + a_1 + a_2 + a_3 + a_4 \quad (5)$$

where

a_1 = walk-wait time,
a_2 = time by car,
a_3 = train journey units, and
a_4 = non-line-haul transit cost.

To allow for the convenience of travel by each mode, Watson developed a simple variable measured in terms of the number of phases of a trip. The best model implies that, for a longer journey (such as recreational), the traveler compares the absolute speed of the car with the sum of the inconveniences resulting from the journey by train. Unable to estimate a value of travel time from this model, Watson used a suboptimal model:

$$\text{Choice of mode} = a_0 + a_1 \frac{(t_1 - t_2)}{\frac{1}{2}(t_1 + t_2)} + a_2 \frac{(c_1 - c_2)}{\frac{1}{2}(c_1 + c_2)} \quad (6)$$

where

t_1 = time by train,
t_2 = time by car,
c_1 = train cost, and
c_2 = car cost.

This model (equation 6) replaces the urban commuter model and incorporates simple time and cost differences with a functional form that allows for the effect of the total length and total cost of the trip. This appears most plausible for the longer and more costly interurban trip. Because Watson considered it difficult to say whether a traveler would base his or her assessment on the faster or slower time, it was decided to use the mean of the two times and the two costs to indicate total journey time and journey cost respectively. A mean value of time of 53 p/h (equal to 67.5 percent of the average wage rate) was estimated. However, from Watson's study, it can be concluded that a value of time could not be estimated from the best model. This result is important since it indicates that the derivation of a time value from an apparent time-cost trade-off situation may not be universally valid, since, in some cases, what appears to be a trade-off situation may not be perceived as such by the travelers. This finding gives support to the perceived measurement of the relevant variables (rather than manufactured measurement). It was not possible to examine the behavior of value of time across income groups because time and cost variables do not appear together in any of the models calibrated for the separate income groups. Hensher (54) in a route choice study derived values of time for personal business, social-recreation, and work purposes. He used a direct valuation procedure that explicitly related the time and cost differences between two interurban routes by a parameter that was a direct estimate of the value of time in which the cost difference was a toll.

The existence of only one route choice situation in Australia limited the variance in the time and cost differences between the two routes required for successful measurement by the binary (logit) estimation procedure. A transfer payment, defined as the amount of change in cost that would have to occur for an individual to consider changing route, was introduced to analyze the point of potential substitution between routes with respect to cost and time, where time incorporated both the opportunity cost and disutility cost of time. Any criticism of this approach would be the same as that given to the willingness-to-pay approach discussed previously. Further theoretical and empirical assessment of the relationship between the opportunity and disutility costs of time has recently been undertaken and will be reported in due course. Only door-to-door values were derived. The absence of any information on income prevented an equivalent wage rate percentage from being provided.

CONCLUSIONS

This paper has attempted to emphasize the most important empirical contributions to the valuation of travel time under varying circumstances Nearly all the studies have estimated values of travel time as by-products of single or simultaneous travel choice and demand models in which the emphasis is on prediction rather than on capturing the conceptual essence of the notion of the value of travel time. Certain underlying requirements for mode choice, such as representation of all trading and nontrading situations, are not consistent with the valuation requirement of individuals who actually face a true time-cost trade-off situation.

Australian evidence for commuter trips indicates that, when the total mode choice sample is used to estimate the value of time, a somewhat lower value than the true value is obtained (26). Many of the studies (29, 32, 38) produced dubious values because of this procedure. With the exception of the work by Hensher (15, 26) on the valuation of business air travel time and commuter mode choice and the research by Hensen (24), there has been difficulty in isolating the true (or pure) value of travel time from a composite time-comfort (and convenience) value. The values derived from mode choice studies are a composite of the pure value of time (a mode abstract measure), any comfort and convenience differences that are a function of changes in activity time within a given mode, and comfort and convenience differences associated with mode switching where the disutility difference intensity is a function of the absolute amount of activity time. This composite value has led to difficulties and general confusion in the application of values to particular modes. As a working rule, the pure value of travel time should be mode abstract and only modified in the context of a particular mode to make allowance for comfort and convenience differences (assuming that there is no separate value of comfort or convenience differences).

A number of researchers are currently trying to identify, quantify, and value (in a relative sense) those nontime cost influences on various travel choices so that the relatively independent valuation components can eventually be isolated. Although early attempts to remove the value of comfort differences associated with mode switching from the value of time have been successful (26), no one has yet isolated the other nontime influences. The continuing research into preferences in nonmarket situations should be encouraged. This need is consistent with the requirement for efficient estimation of the value of time and the requirement to separate the opportunity cost of time and the disutility of time spent traveling.

The majority of the studies discussed have produced single total sample values of travel time savings due largely to the inadequate sample sizes required for stratifications and have resulted in insignificant income-related values. Seven studies found the VTTS to be directly related to income, two studies found the VTTS to be a constant proportion of income, two studies found the VTTS to be less than a constant proportion of income, one study found the VTTS to be greater than the constant proportion of income, and one found the VTTS to be an increasing function of income below mean income and a decreasing function above mean income. The general view is that the VTTS is a function of income, but more research on larger data bases is required to test this hypothesis. Even though there is a diversity of single values, they do tend to show some semblance of consistency when converted to international units (67). Even allowing for problems of international and interpersonal comparisons of values and utility, the studies discussed suggest that the VTTS tends to range in value from a high for working time through business travel time and commuting time to a low for nonwork, noncommuting time. A definite trend in technique is emerging.

Before improved (stratified) empirical estimates can be made, improvements to the procedures previously used to obtain estimates are required. For some journey purposes (e.g., commuter trips), these improvements are relatively small; for other trips (e.g., recreation trips), the improvements appear to be enormous (69).

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