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The Costs and Benefits of Telecommuting: An Evaluation of Macro-Scale Literature

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ABSTRACT

This literature review has been prepared to synthesize and assess previous large-scale evaluations of telecommuting. First, a conceptual framework is proposed to organize the inputs and outputs of a macro-scale telecommuting benefit-cost analysis. Then, four federal and regional reports are examined in terms of methodology, assumptions, economic approach, and major findings. This review identifies common inputs and discusses the critical assumptions that routinely affect the results. Finally, the economic approaches and major findings are presented and compared.

Keywords: telecommuting, telecommunication, benefit cost analysis.

EXECUTIVE SUMMARY

In this paper, we outlined a conceptual framework by which cost-benefit analyses of telecommuting should be conducted. We noted that an economic evaluation of telecommuting should ideally begin by identifying the scale, perspective, and scope of the study, and by establishing the base case conditions. Additionally, it was noted that an economic approach with appropriate discounting methods must be selected before the costs and benefits can be computed. The actual benefits and costs can be computed and evaluated once the analysis data and computational parameters have been defined.

This paper also took a critical look at four macro-scale economic evaluations of telecommuting. The evaluation began by recognizing that a specific set of critical parameters and major assumptions must be explicitly addressed within any economic evaluation of telecommuting. These of critical parameters and major assumptions include:

- the current number of telecommuters
- the frequency of telecommute "events" by each telecommuter
- the number of vehicle miles of travel (or travel time) foregone by telecommuting
- the assumed growth (change) in the number of telecommuters
- the assumed average discount rate
- the allocation of costs among each sector (public, employer, employee)

Additionally, it was noted that studies should contain sensitivity analysis around key unknown parameters, such as assumed growth in the number of telecommuters and future discount rates. This is particularly important when the critical assumptions are assumed and not based on empirical work.

While the use of a spreadsheet model with macro-scale estimates appeared to be a commonly accepted and practiced approach to estimate the potential benefits of telecommuting, this approach was not always employed without shortcomings. Specifically, it was apparent in these studies that there was a failure to account for most costs as well as a failure to fully monetize most results. Telecommuting can be properly evaluated only after shortcomings such as these are addressed.

Additionally, we prepared a brief discussion of each individual study's findings. The major quantified or monetized results are presented with each study. The use of different assumptions and economic techniques, however, makes any quantitative comparison of the results difficult. Nonetheless, the results obtained by each of these studies were examined, along with conclusions about the effects of telecommuting on travel. In general, the results indicated that the cost and benefit elements that were included in these reports, and the extent to which each element was evaluated, vary from study to study.

Ultimately, these preliminary findings should be taken into account when developing a more robust and accurate model that evaluates the economics of telecommuting. This model will, in turn, indicate the expected economic outputs by telecommuters, their employers, and the public sector, given assumed levels of foregone travel. The final evaluation results can then be used by transportation analysts to compare and evaluate the cost-effectiveness of telecommuting with other transportation demand measures.

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1.0. INTRODUCTION

In recent years, the concept of telecommuting has received considerable attention, from the media, from would-be practitioners, from employers, from potentially affected industries (telecommunications services, home office suppliers) and from public planners and policymakers. On net, telecommuting is perceived by many of these parties to have important personal, organizational, social, economic, transportation, and environmental benefits. These benefits have been documented to varying degrees in the academic and popular literature. For example, any number of mass-market books (Kugelmass, 1995; Nilles, 1994; Gray *et al.*, 1993) on implementing telecommuting (from the perspective of the employee, the employer, or both) describe, conceptually and anecdotally, various benefits as well as potential disadvantages (while finding that the former outweigh the latter when telecommuting is appropriately applied).

The advantages and disadvantages of telecommuting have been evaluated from the perspective of the employer (Bernardino and Ben-Akiva, 1996; Duxbury *et al.*, 1987; Yen *et al.*, 1994) and employee (DeSanctis, 1984; Gordon, 1976; Hesse, 1995; Katz, 1987; Mahmassani *et al.*, 1993; Mokhtarian and Salomon, 1997; Varma *et al.*, 1997; Salomon and Salomon, 1984; Sullivan *et al.*, 1993). On the transportation and environmental side, a sizable number of studies have documented the benefits at the individual and program level (Hamer *et al.*, 1991, 1992; Henderson *et al.*, 1996; Koenig *et al.*, 1996; Pendyala *et al.*, 1991), while some have expressed caution about extrapolating those benefits to an aggregate or systemwide level (Mokhtarian *et al.*, 1995; Salomon, 1984, 1995; Mokhtarian, 1997). Others, such as Dagang (1993) and Nelson and Shakow (1995), have examined the effectiveness of telecommuting compared to the effectiveness of other transportation demand management measures.

Some of the telecommuting advantages and disadvantages that have been identified in the aforementioned studies have obviously included various costs and benefits. However, it is notable that the determination of which benefits or which costs were included, or conversely which were ignored, has largely not been addressed. As will also be seen, those studies that do go into some depth on the economic evaluation of telecommuting have often lacked appropriate discounting methods and characterization of variable uncertainty. In part, this lack of a systematic accounting of benefits and costs and their uncertainties, has been a function of the evolution of telecommuting itself; as the practice of telecommuting has grown so also has an understanding of the range of plausible benefits and costs. This paper contributes to the current body of knowledge by first presenting a conceptual framework for identifying costs and benefits and organizing an economic evaluation of home-based telecommuting, and second, by presenting a rigorous review, within the conceptual framework, of the assumptions, inputs, and outputs of a selected set of studies.

The paper begins with a presentation of the conceptual framework proposed for organizing the inputs and outputs of a macro-scale telecommuting benefit-cost analysis. In this section, we also introduce each of the studies used in the remainder of the review. For each study we present an overview, noting the motivation for conducting the study, and the setting (i.e., public or private) of the study. The third and fourth sections utilize the conceptual framework to examine the benefits and costs each study chose to include and the assumptions and data used as the basis for computing the benefits and costs in each of the studies. We then compare the economic approaches and the major findings of each study. Finally, recommendations are made for future research.

2.0. CONCEPTUAL FRAMEWORK FOR TELECOMMUTING BENEFIT-COST ANALYSES

In general, an economic evaluation of telecommuting should ideally begin first, by identifying the scale, perspective, and scope of the study, and second, by establishing the base case conditions. Beginning with the study scale, two levels of analysis can be identified: macro-scale and micro-scale. The micro-scale studies focus on the individual behavior of telecommuters or telecommuters within a company or organization. In these studies, the interest lies primarily in estimating the private sector costs and benefits that will accrue from telecommuting. Alternatively, macro-scale studies are typically more concerned with estimating the aggregate costs or benefits that can result when considering the population of all possible telecommuters. Here, the primary emphasis is on identifying the public costs and benefits associated with telecommuting.

Because some costs may also be considered cross-sector benefits (e.g., public sector subsidies for private-sector telecommuting) and vice-versa, ideally a "point of view," or perspective is made explicit at the onset of the study. The adoption of a perspective clarifies any limitations associated with what constitutes a cost or a benefit. Each perspective should also be accompanied by a definition of the project scope. For example, is only home-based telecommuting to be considered in the analysis, or is a regional network of telecommuting centers assumed? The project scope is also somewhat dependent upon the perspective adopted. The pure home-based telecommuting option will usually correspond to no publicly funded telecommuting centers. Likewise, when publicly funded centers are involved, the possibility of center-based telecommuting arises in the private sector.

Additionally, a base case should then be established for each of the identified project scopes. Clearly specifying the base case allows for consistent quantification and comparison of benefits and costs across project scopes. The base case is usually considered the status quo or the alternative in which no costs or benefits are incurred. A properly defined base case should identify a starting reference, current traffic conditions, and any applicable trip reduction policies.

The private sector base case might also include additional assumptions regarding the type of business, current employee demographics, and the availability of parking and/or building infrastructure.

Once the study scale, perspective, and scope and the base case conditions have been established, the costs and benefits to be included in the study can be defined. A wide range of costs and benefits has been identified in the telecommuting literature. Table 1 presents a preliminary inventory of the types of benefits and costs that have been identified (but not necessarily measured or monetized) in prior research and practice. Note that we have also identified costs and benefits that may be assigned to the individual. In some cases, the employer may lower its costs of telecommuting by transferring some of the associated costs (e.g., equipment, utilities, or space) to the individual. That is, the individual's willingness to pay for some of the costs of telecommuting represents a benefit to the employer. Finally, it is important to note that the inclusion of an item in the table does not necessarily imply that it will be considered material once it is critically examined. Inclusion connotes only that the factor has been identified or used in one or more prior studies evaluating telecommuting.

Regardless of the costs and benefits ultimately chosen for inclusion in an analysis, a large number of assumptions and additional data will be required to estimate these costs and benefits. Although it is difficult to know precisely what range of additional data or assumptions might be required in an individual study, every study will have to address certain fundamental issues in order to estimate any benefits or costs. As we will discuss in subsequent sections, such fundamental issues include estimating the current and future number of telecommuters, defining the number of telecommuting events, and assessing the change in travel demand due to telecommuting.

To complete the economic evaluation, an economic approach must be selected and the costs and benefits actually computed. There are many possible methods for comparing benefits and costs. Traditional economic measures include the internal rate of return (IRR), net present value (NPV), and the benefit-to-cost ratio (B/C). Other contemporary approaches that have been explored in the transportation literature include sufficiency ratings (McFarland and Memmott, 1987), cost-effectiveness criteria, and multi-criteria evaluation (Lewis, 1991; Maggio *et al.*, 1996; Niemeier *et al.*, 1995). The NPV is known to be the best measure of economic merit for guiding project investment (Lewis, 1991). Alternatively, the B/C ratio serves as a measure that allows project worth to be assessed without discriminating against higher cost projects. When properly applied, all measures yield similar outcomes.

Table 1. Costs and Benefits Associated with Telecommuting

		COSTS	BENEFITS
Public	Start-up	〈 marketing/training development 〈 evaluation	(none)
	Ongoing	〈 ongoing marketing/training 〈 latent demand realization 〈 urban sprawl	〈 travel reduction (direct) 〈 emission reduction (direct) 〈 improved highway safety 〈 increased economic development (employment opportunities for underemployed/mobility-limited labor segments) 〈 increased neighborhood safety
Private	Start-up	〈 planning 〈 marketing/training 〈 equipment	(none)
	Ongoing	〈 internal program administration 〈 marketing/recruitment 〈 training 〈 equipment maintenance/ replacement (less salvage) 〈 communication 〈 decreased workplace interaction/ immediate access 〈 security of data	〈 space cost savings (office and parking) 〈 recruitment (access to best talent and broader labor markets) 〈 improved retention 〈 increased productivity ϒ less absenteeism ϒ less sick leave ϒ longer hours ϒ fewer distractions (greater productivity per hour) 〈 improved customer service 〈 disaster recovery 〈 public relations 〈 compliance with air quality/trip reduction regulations
Individual	Start-up	〈 equipment 〈 software 〈 stress to perform	(none)
	Ongoing	〈 communication costs 〈 utility costs 〈 space costs 〈 decreased workplace interaction 〈 loss of support services 〈 loss of boundary between work and home	〈 travel time/stress savings 〈 travel cost savings 〈 other cost savings 〈 personal flexibility 〈 reduced work-related stress 〈 ability to get more/better work done 〈 ability to work while mobility limited or physically distant from workplace 〈 more time with family

Employing a benefit-cost analysis also requires the specification of a discount rate, project life, and the timing of project benefits. The selection of a discount rate is associated both with the different theoretical perspectives (e.g., neo-Classical, Keynesian, etc.) and with market imperfections. Theoretically, the discount rate balances the marginal rate of productivity (the rate of productivity of the last dollar invested) and the marginal rate of time preference. The "appropriate" discount rate has been the subject of numerous debates that will not be addressed in this paper. However, ideally an economic evaluation would be conducted on a range of discount rates (which, on one extreme, may reflect the private market rates and on the other, judgments about the social rate of discount).

Specifying the project life and the timing of the costs and benefits are clearly complex issues for any of the telecommuting project scopes we have identified. In traditional transportation investment analyses, the project life is usually taken to be a function of the infrastructure longevity; for example, pavement life typically ranges from 5-10 years while a 20-year life is usually assumed for new roadways. In contrast, telecommuting alternatives, such as a telecommuting center, might have leased building infrastructure and incremental equipment upgrades, thus limiting the applicability of the infrastructure "duration" as a means of specifying project life.

Once all of the analysis data and computational parameters have been defined, the actual benefits and costs can be computed. It is important to recognize that two sources of uncertainty often exist with the data and parameters used in the actual calculations: the uncertainty associated with future events and the uncertainties associated with data precision. Uncertainty associated with future events might include variability in the cost of travel or in the projected future traffic volume growth. Regardless of the nature of the uncertainty, it is useful to test a range of values and assess the impacts of varying assumptions on the final outcome.

In the following sections, we utilize the proposed conceptual framework to review four prominent studies evaluating the economics of telecommuting. These studies are considered state, regional, or federal macro-scale studies that rely on aggregate estimates of the number of telecommuters; the estimated number of telecommuters is often used to estimate potential changes in travel behavior which are then transformed into costs and benefits.

Both micro-scale and macro-scale (and private-public) perspectives are necessary to showcase the full impact of telecommuting. While the macro-scale studies present aggregate assessments of the societal benefit of telecommuting, micro-scale studies remain important because they address issues that are often ignored or overlooked by the large-scale studies. Conversely, not all of the micro-scale studies consider the same benefits as macro-scale studies. For example, some micro-scale studies consider the benefit of increased productivity as a result of telecommuting, while macro-scale studies often do not address these benefits. Meanwhile, most macro-scale studies consider the benefits to air quality as a result of telecommuting, while micro-scale studies often neglect these benefits. While this paper focuses on macro-scale studies, current research is being conducted which reviews and evaluates the literature of micro-scale studies.

It should be noted that many of these past studies do not claim to be and should not be considered rigorous economic cost-benefit analyses. These reports make no attempt to evaluate the full set of benefits and costs of telecommuting. Instead, their focus is primarily on identifying the potential benefits of telecommuting.

The four macro-scale studies examined in this literature review are:

〈 an Arthur D. Little, Inc. study titled *Can Telecommunications Help Solve America's Transportation Problems?* (Boghani *et al.*, 1991);

〈 an MBA thesis by Stephen Finlay titled *Benefits, Costs, and Policy Strategies for Telecommuting in Greater Vancouver* (Finlay, 1991);

〈 a U.S. Department of Transportation (DOT) study, *Transportation Implications of Telecommuting* (DOT, 1993), and

〈 a U.S. Department of Energy (DOE) study, *Energy, Emissions, and Social Consequences of Telecommuting* (DOE, 1994).

Can Telecommunications Help Solve America's Transportation Problems? (Boghani et al., 1991)

Conducted by Arthur D. Little, Inc. (ADL) and funded by several telecommunication companies, the purpose of this study was to "provide an independent, objective, transportation-oriented quantification of the benefits to society from substituting transportation activities by activities performed using telecommunications infrastructure" (p. 1, Boghani *et al.*, 1991).

In many respects, this study has similar goals to the DOT and DOE reports we will review later. All three studies share (sometimes overly) optimistic assumptions of the levels of national telecommuting acceptance and practice in their effort to illustrate the potential benefits of telecommuting. Additionally, the methodologies for identifying and computing telecommuting benefits are also very similar. The ADL study used aggregate data from published government and commercial sources to estimate: 1) travel reductions due to telecommunications substitution; 2) the benefits due to the estimated travel reductions, and 3) the dollar value associated with the estimated benefits.

Benefits, Costs, and Policy Strategies for Telecommuting in Greater Vancouver (Finlay, 1991)

Finlay's (1991) report, entitled "Benefits, Costs, and Policy Strategies for Telecommuting in Greater Vancouver," constituted his MBA thesis requirement at Simon Fraser University. As the title suggests, the purpose of the report was to evaluate the public policy strategies "by which telecommuting could be promoted" (p. iii, Finlay, 1991). With financial assistance provided by the British Telephone Company, this paper was written to develop a "quantitative relationship between the amount spent to promote telecommuting and the incidence of telecommuting." In other words, the study's major objective was to develop a hypothetical relationship between government spending in support of telecommuting and the resulting benefits from expected levels of telecommuting. The relationship is hypothetical, because the author acknowledges that "no relevant empirical data exists" with which to actually test the relationship between government spending and the incidence of telecommuting (p. ii, Finlay, 1991). Despite its shortcomings, it will be shown that this report is significant to the literature because it attempts to make an economic evaluation of telecommuting from a regional perspective by taking advantage of unique regional budgeting methods.

Transportation Implications of Telecommuting (DOT, 1993)

While several studies in the 1970's and examined the potential energy impacts of telecommuting (e.g. Harkness, 1977; JALA, 1983; Jones, 1973; Kraemer, 1982; Kraemer and King, 1982; Lathey, 1975; Obermann *et al*., 1978), the U.S. Department of Transportation (DOT, 1993) study represents one of the more recent large-scale federal research projects on the benefits of telecommuting. The study was required by Section 352 of the 1992 Department of Transportation and Related Agencies Appropriations Act. Co-sponsored by the Department of Energy (DOE) and the Environmental Protection Agency (EPA), the primary objective of the study was to evaluate current and future impacts of telecommuting on transportation, the environment, and energy use.

Prompted by public transportation agencies struggling to relieve local highway congestion and meet legislative air quality mandates, the DOT examined the direct near-term (five to ten year) impact of telecommuting on traffic. The goal of the report was to provide information to facilitate the formulation of government policies regarding telecommuting "based primarily on a careful examination of the large and diverse body of literature on the subject" (p. 3, DOT, 1993). As noted in the report, the study was conducted while other federal and state agencies were already recommending telecommuting strategies in legislative initiatives and encouraging efforts to foster and promote telecommuting as a travel reduction measure (DOT, 1993).

Using a spreadsheet-based model, the study generated the number of commute trips, and the vehicle miles of travel (VMT) attributable to these trips, that were supplanted by telecommuting. The DOT study estimated other direct transportation non-monetary effects such as emission reductions and reduced accident deaths. Those effects that could be easily monetized, such as gasoline savings, were converted to dollar units. For example, gasoline savings were monetized by multiplying estimated amounts of conserved gasoline with the current market price of gasoline. Other effects were not monetized. According to John B. Hopkins of the DOT, "The economic conversion was not mandated [by the Related Agencies Appropriations Act], and we chose to avoid the complexities and contentiousness of evaluating time, discounting lives saved, etc." (personal communication, April 1997).

The study also defined an extensive list of the non-discounted costs and benefits of telecommuting with respect to the employer, the employee, the transportation planner, the telecommunications industry, and society in general. Despite being developed with "a very limited foundation of data" (p. 3, DOT , 1993), this report still represents a relatively comprehensive attempt to quantify the benefits of telecommuting. Moreover, the report recognized telecommuting as a viable travel demand management tool and provided information which could lead to improved telecommuting data collection and research.

Energy, Emissions, and Social Consequences of Telecommuting (DOE, 1994)

The Department of Energy conducted "a study of the potential costs and benefits to the energy and transportation sectors of telecommuting" as required in Section 2028 of the Energy Policy Act of 1992 (p. ix, DOE, 1994). The objective of the DOE study was to expand the earlier DOT study assessments of the economic and social impacts associated with increased levels of telecommuting and to examine the indirect effects of telecommuting on urban traffic (i.e., improved traffic flow, latent demand, and increased urban sprawl). Specifically, this report focused on the energy and emissions aspects associated with telecommuting. The study partially relied on the several estimates made by the earlier DOT study.

Referring to Table 2, the study created sixteen different hypothetical scenarios by assuming different combinations of the design year (2005 vs. 2010), the distribution of types of telecommuting (i.e., different proportions of home-based and telecenter-based telecommuters), urban structure, and emissions levels. The emissions assumptions included a low-emission vehicle (LEV) scenario, which assumed universal use of reformulated gasoline and year 2004 inspection and maintenance requirements, and a high-emission vehicle (HEV) scenario which assumed neither. In addition, the study also examined the latent demand effects of adding effective new highway capacity due to the substitution of travel with telecommuting and the effects of changes in urban density due to telecommuting.

Table 2. DOE Scenarios

Future Year 2005								Future Year 2010							
DOT Telecommuting Assumptions				"Alternative" Telecommuting Assumptions				DOT Telecommuting Assumptions				"Alternative" Telecommuting Assumptions			
Urban Sprawl Adjustment		No Urban Sprawl Adjustment		Urban Sprawl Adjustment		No Urban Sprawl Adjustment		Urban Sprawl Adjustment		No Urban Sprawl Adjustment		Urban Sprawl Adjustment		No Urban Sprawl Adjustment	
LEV	HEV	LEV	HEV	LEV	HEV	LEV	HEV	LEV	HEV	LEV	HEV	LEV	HEV	LEV	HEV

One of the study's contributions is a link to monetization of avoided vehicle emissions attributed to the estimated travel impacts of telecommuting. Using emissions factors generated by the EPA Mobile 5 emission model, the report provides emission cost estimates and allows the reader to calculate the emissions costs by assuming the costs from emissions are equal to: 1) the avoided cost of pollution control measures or 2) estimates of their damage. The avoided cost of pollution control measures is considered to be equal to the estimated cost of removal and is noted in research by Greene and Duleep (1992); the costs of emissions damage is based, largely in part, on estimates of health-related problems caused by pollutants (classified as carcinogens) and is noted in research by Wang *et al.* (1993). The DOE study was probably the first attempt to introduce these methods of quantifying air quality benefits due to telecommuting. Attempts to account for impacts on urban form and latent demand were also notable contributions.

3.0. DATA INPUT AND ANALYSIS ASSUMPTIONS

In this section, the various data sources and assumptions used in the telecommuting studies reviewed here are compared. A discussion of general macro-scale requirements is followed by an analysis of the various data sources and assumptions used in past studies. It will be shown that the macro-scale studies share similar requirements and assumptions as well as shortcomings.

The review indicates that many critical assumptions have not been treated as assumptions in past studies while others have either been used without sufficient justification or ignored altogether. Based on our review, the macro-scale analyses have a critical dependence on the input variables shown in Table 3. One set of critical values is used to quantify the transportation impacts of current levels of telecommuting, while the second set is necessary to quantify the transportation impacts of expected future levels of telecommuting.

Table 3. Key Macro-Scale Telecommuting Parameters

Variables Required to Estimate the Transportation Impacts of Current Levels of Telecommuting	Variables Required to Estimate the Transportation Impacts of Expected Levels of Telecommuting
〈 number of telecommuters 〈 frequency of telecommute "events" by each telecommuter 〈 vehicle miles of travel (or travel time) foregone by telecommuting (usually an average per telecommute "event")	〈 expected growth in total telecommuters 〈 expected change in frequency of telecommute "events" by each type of telecommuter (or the expected change in distribution of each type of telecommuter) 〈 expected growth in VMT

The critical variables include the number of times individuals substituted travel with telecommuting, and how much travel (VMT or time) was foregone during each telecommuting occasion. The change in VMT (or travel time) is used to calculate other concomitant benefits, such as gasoline, emissions, and roadway infrastructure savings. It is important to note that while additional assumptions are necessary to arrive at values for these other benefits, almost all calculations originate with the three critical variables noted in Table 3.

To estimate future impacts of levels of telecommuting, the critical variables must be forecasted based on known or assumed telecommuting trends. Unfortunately, the results of the analysis become much more uncertain in this case, because little empirical data exists that can be used to forecast trends or validate past forecasts.

3.1. Current and Expected Number of Telecommuters

Perhaps the most critical variable in the estimation of telecommuting costs and benefits is the number of telecommuters. For the macro-scale studies, where regional or national estimates are needed, the total number of estimated telecommuters is usually based on the total number of "information workers" in the labor force.[1] A subset of information workers, whose job performance is "independent of the location of the worker" are assumed to be candidates for telecommuting (p. 305, Nilles, 1988). Methodologically, the national estimates of telecommuters are derived from an estimated fraction of information workers which in turn is estimated from national labor statistics of individuals estimated to be in the work force as shown in Figure 1 (e.g., DOT, 1993).

Figure 1. The Telecommuting Universe

Source: DOT, 1993

More recently, however, it has been noted (Mokhtarian, 1991a, 1991b) that a number of people not considered to be in "information worker" occupations are in fact telecommuting (e.g., police and probation officers, restaurant inspectors, health care workers, etc.). Hence, the segment of the workforce whose jobs are amenable to telecommuting is probably larger than previously believed. On the other hand, the extent to which constraints other than job title are preventing telecommuting has probably been underestimated. For example, in one sample, containing 95% information workers, 44% of the sample indicated that their jobs were not suitable for home-based telecommuting any amount of time (Mokhtarian and Salomon., 1996). Constraints other than job suitability are also at work as well. To some unknown extent, these effects (underestimating both the size of the potential telecommuting universe based on job title, and the extent to which constraints other than job title are binding) counteract each other.

In general, it remains unclear how accurately the number of potential telecommuters can be derived from estimates of the number of information workers. Nilles, who originated this forecasting approach, has acknowledged that it remains difficult to verify even the current levels of telecommuting, let alone predict future levels:

> These few documented studies . . . do not show how many telecommuters there are today. Nor do they show how many there will be in 5, 10 or 20 years. They also fail to point out what the distribution of modal choices in telecommuting will be. (p. 305, Nilles, 1988)

Despite limited empirical data on the current levels of telecommuting, Nilles extrapolates future levels using estimated current levels of telecommuting. However, employing this method to forecast levels of telecommuting requires an additional assumption – an estimate of the growth in the number of telecommuters. In 1987, Nilles assumed both a linear and exponential growth function. Alternatively, in 1991 he assumed a logistic growth function. All three forms can be fit to the limited available data, with each yielding different results.

All of this is important to note, because Nilles' estimates and/or related methodology have been referenced throughout the telecommuting literature, including the DOT, DOE, and Boghani *et al.* studies. The repeated use of Nilles' approach has certainly increased the likelihood of repeating any errors when new research efforts have depended upon this data for estimating future levels of telecommuting. Essentially, the estimated current levels of telecommuting remain the basis from which future levels of telecommuting are extrapolated – which in turn affects the results of any projected macro-scale cost-benefit analysis.

Table 4 presents how estimates of telecommuters were derived in the DOT (1993) report using Nilles' methodology. The assumptions used to derive the estimates include: growth in the labor force, the percentage of information workers in the labor force, and the adoption of telecommuting by information workers. In 1991, the number of telecommuters was predicted to increase from 2 million in 1992 to 15 million by the year 2002, which represents an average annual increase of 20.2%.

Table 4. Current and Expected Number of Telecommuters in DOT Study (1993)

Year	U.S. Population[a] (millions)	Labor Force[b] (millions)	Information Workers[c] (millions)	Telecommuters[d,e] (millions)
1992	253.3	127.6	72.1	2.0
1993	255.2	129.1	73.3	2.5
1994	256.9	130.7	75.6	3.2
1995	258.7	132.3	75.7	4.0
1996	260.5	133.9	76.8	5.0
1997	262.3	135.5	78.2	6.2
1998	264.1	137.1	79.6	7.6
1999	266.0	138.7	81.0	9.2
2000	267.8	140.4	82.5	10.9
2001	269.7	142.1	84.0	12.9
2002	271.6	143.8	85.5	15.0
Avg. Annual Growth Rate	0.7%	1.2%	1.7%[f]	20.2%[f]

Source: DOT (1993). (See p. 55 and p. 59, DOT, 1993.)

a. Based on Bureau of Census estimates (not referenced).
b. Based on 1988 Bureau of Labor Statistics projections.
c. Based on projections made by Nilles (Telecommuting Research Institute, 1991) from classifications of standard occupations as "information workers" by Porat (1977). DOT assumes that "information workers constitute 56% of the U.S. workforce and gradually increase to around 59% in 2002" (p. 54, DOT 1993).
d. Based on projections made by Nilles (Telecommuting Research Institute, 1991).
e. These numbers represent the DOT "upper bound." To "reflect the uncertainty in the analysis," the DOT authors also created a "lower bound" scenario. The number of telecommuters in the "lower bound scenario" was simply set as half of number of telecommuters the "upper bound scenario."
f. Calculated by the authors of this paper, using a compounding interest rate function, $i = (-\ln(P/F))/N$, where P is present year value, F is the future year value, and N is the time between P and F.

In 1994, the DOE used Nilles' methodology to develop growth functions for the expected share of information workers and the share of telecommuters in the labor force. The coefficients in the new growth functions were extrapolated from DOT using ordinary least squares regression extrapolations.[2] "Logistic curves were fitted to the DOT data and used to extrapolate projections to 2005 and 2010" (p 85, DOE, 1994). It is important to note that the "data" used by DOE are actually Nilles' forecasts contained in the DOT report, not empirical data. Table 5 presents how estimates of telecommuters were derived in the DOT report using Nilles' methodology.

Using the equations provided in the DOE report, estimates for the number of information workers and the telecommuting labor force can be back-calculated from the number of telecommuters (Table 5) and compared with those values presented in the DOT study (Table 4). While there might appear to be discrepancies between both the estimated numbers of information workers and the estimated numbers in the labor force, it is important to note that the DOE study assumes telecommuting market penetration only for "the 339 largest U.S. cities (about 2/3 of the nation's population)" (p. xx, DOE, 1994), while the DOT derives its potential telecommuters from the entire U.S. population and the entire U.S. labor force. Nonetheless, we can see that the average annual growth of the labor force and the information workforce is consistent with those presented in the DOT study – as one would expect, given that the DOE telecommuter estimates are still derived from the DOT telecommuter estimates. Additionally, we can see that, although it extrapolates much farther into the future, the DOE has a lower average annual growth rate for telecommuters (15.5% over 22 years) than the DOT (20.2% over 10 years).

Table 5. Current and Expected Number of Telecommuters in DOE Study (1994)

Year	U.S. Population (millions)	Labor Force[a] (millions)	Information Workers[a] (millions)	Telecommuters (millions)
1988[b]	N/A	71.4	38.5	0.5
2005	N/A	106.0	63.7	17.7 [c]
2010	N/A	106.2	64.8	29.1 [c]
Avg. Annual Growth Rate	N/A	1.2%[d]	1.6%[d]	15.5%[d]

a. Back-calculated by the authors of this paper from given number of telecommuters, using the functions shown in this paper on at the bottom of page 9. The functions are originally from page 85 of the DOE study.
b. Based on projections made by Nilles (Telecommuting Research Institute, 1991).
c. Projected by DOE.
d. Calculated by the authors of this paper, using a compounding interest rate function, $i = (- \ln (P/F)) / N$, where P is present year value, F is the future year value, and N is the time between P and F.

Additionally, Figure 2 presents the extrapolated adoption levels in the DOT and DOE studies. From this figure, we can see how the DOT extrapolated its projections based on Nilles' projections, and how the DOE extrapolated even farther from the DOT projections.

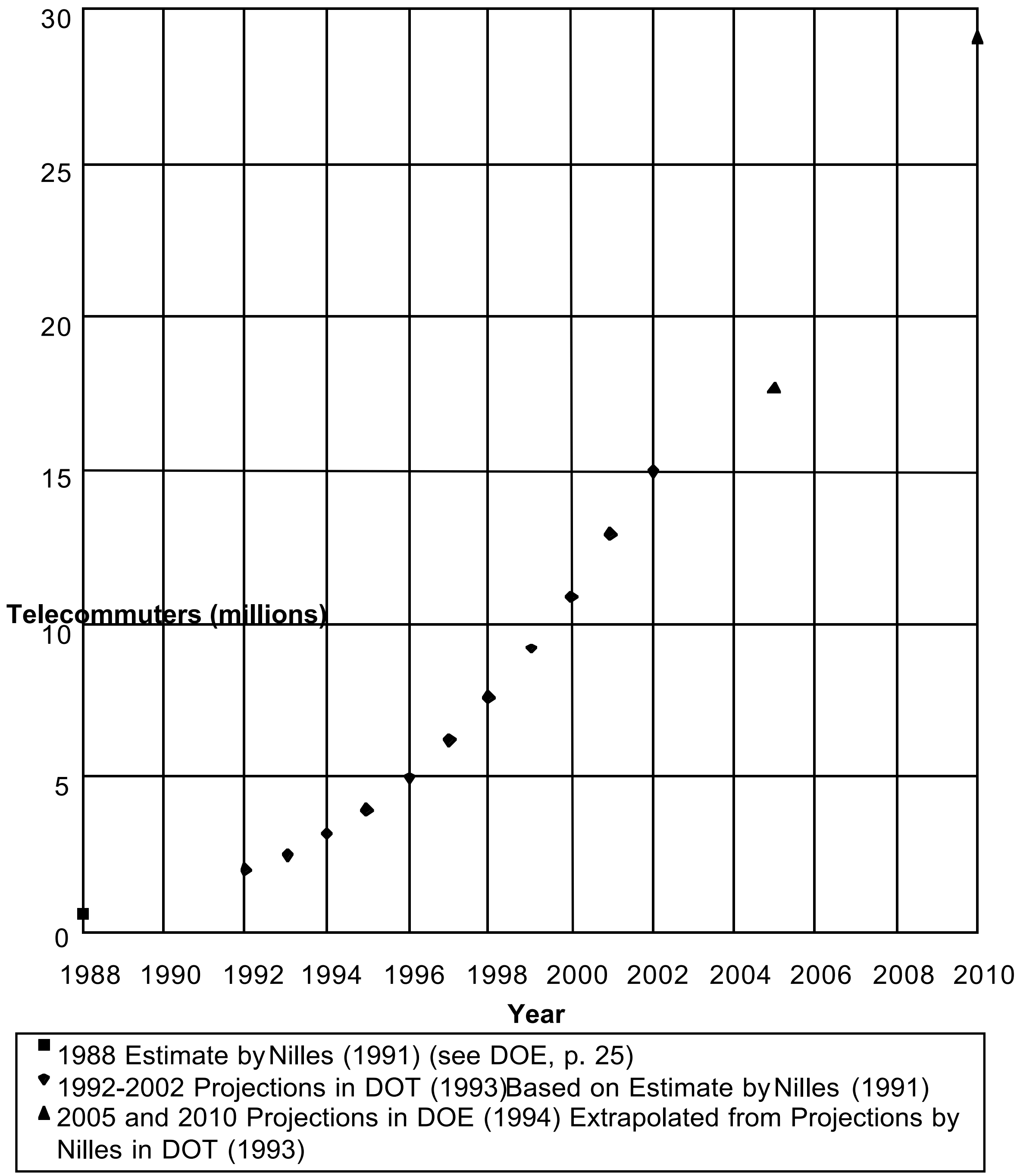

Figure 2. Projected Numbers of Telecommuters

The study by Boghani *et al.* is unique among the studies which rely on Nilles' forecasting methodology. While the authors still assume that telecommuters constitute a subset of information workers, they do not attempt to estimate current numbers of telecommuters.

Instead, they simply assume for the sake of analysis that 12% of the estimated information workers who commute to work will adopt telecommuting *and* substitute vehicle travel with telecommunications from home on any given day. Since their analysis is set in 1988 in terms of population and labor force assumptions, they are in effect analyzing the hypothetical impacts which would occur if 12% of information worker commute trips in 1988 were replaced by telecommuting. They do not forecast trends in the adoption of telecommuting. Essentially, it is assumed that that *12% of all urban commute trips by information workers* could be substituted with telecommunications.

Boghani *et al.* begin with the total number of commuters in the labor force reported in the 1980 NPTS Journey to Work;[3] the 1980 NPTS estimates were adjusted to 1988 figures using an assumed growth rate of 2.3% per year (unreferenced) and disaggregated by urban and rural commuters. Of the commuters in the labor force, a fraction is believed to be information workers. Using 1980 urban occupational data in the 1980 Bureau of Census and a growth rate of 2.75% per year (unreferenced), Boghani *et al.* estimate that 58% of the estimated urban workers commuting to work of those were assumed to be urban "information workers."[4] Finally, the authors assumed that 12% (6%) of the 58% (54%) of the urban (rural) information workers who commute to work will substitute vehicle travel with telecommunications from home. (It is not clear how 6% for the rural substitution level was obtained. It appears to arbitrarily set as half of the urban substitution level.)

While this approach is simpler than Nilles', the assumption that 12% substitution of commute trips by information workers with telecommunications is questionable. While other research is cited in the report, additional analysis of the references reveals that the assumption appears to be too optimistic. A recent analysis finds that previous research does not support a substitution rate over 10%, and states that, "the ADL study's conclusion that a 12% figure is a reasonable substitution rate, is at least in part, not based on the references cited" (p. 24, Salomon, forthcoming). Table 6 presents how the 12% substitution coefficient translates into numbers of foregone information worker commute trips.

Table 6. Estimated Number of Telecommuters in Boghani *et al.* Study (1991)

Year	U.S. Population[a] (millions)	Commuting Labor Force[b] (millions)	Commuting Information Workers[c] (millions)	Daily Work Trips Substituted[d] (millions)
1988 (urban)	183.1	74.6	43.3	5.2
1988 (rural)	64.9	22.9	12.4	0.7
Total	248.0	97.6	55.7	5.9

a. Extrapolated by Boghani *et al.* from 1980 Dept. of Commerce Population Census (assuming a unknown growth rate).

b. Extrapolated by Boghani *et al.* from 1980 NPTS Journey to Work (assuming growth of 2.3% per year, unreferenced).

c. Calculated by the authors of this paper, assuming (as Boghani *et al*.) that 58% of urban commuters' and 54% of rural commuters' trips are made by information workers. These percentages were extrapolated by Boghani *et al.* from occupational data in the 1980 Dept. of Commerce Population Census (assuming a growth rate of 2.75% per year, unreferenced). Boghani *et al*. also refer to the projections made by Nilles (1988) from classifications of standard occupations as "information workers" by Porat (1977).

d. Calculated by the authors of this paper, assuming (as Boghani *et al*.) that12% of urban commute trips and 6% of rural commute trips are substituted by telecommuting.

Additional calculations allow for the comparison of assumed substitution levels in different studies at various points during the study periods, as shown in Table 7. These substitution rates were obtained by multiplying the assumed adoption level by each type of telecommuter with the average frequency of telecommuting events exhibited by each telecommuter (*substitution = frequency * adoption*).

According to Garrison and Deakin (1988) and Nilles (1988), a reasonable level of substitution would be between 5 and 10%. The results of these calculations indicate that Boghani *et al*. assume a high level of substitution for their 1988 analysis, while DOT seems to take a conservative estimate for 1997 and 2002. Meanwhile, DOE expects greatly increased levels of telecommuting by 2010.

Table 7. Comparison of Assumed Levels of Substitution

Year	1988	1992	1997	2002
Study	Boghani *et al*., 1991	DOT, 1993	DOT, 1993[a]	DOT, 1993[a]
Frequency (days/week)	N/A	2.46	2.98	3.51
Frequency (%)	N/A	49.3%	59.5%	70.3%
Adoption[b]	N/A	2.80%	6.08% - 7.91%	8.76% - 17.53%
Substitution[c]	12.0%	1.4%	3.6% - 4.7%	6.2% - 12.3%

a. Range represents difference between "lower bound" scenario and "upper bound" scenario.
b. Percentage of information workers who adopt telecommuting at any frequency. (*adoption = total # of telecommuters ÷ total # of information workers*)
c. Percentage of information worker commute trips substituted by telecommuting. (*substitution = frequency * adoption*)

The estimation of the number of telecommuters is an example of a "snowballing" effect for critical variables in the telecommuting literature (Salomon, forthcoming). "Snowballing" occurs when citations are repeatedly made of past hypothetical results and then of results based on those results, until the hypothetical almost appears empirical. That is, past research is "repeatedly quoted in what seems a self-perpetuating mechanism" (p. 23, Salomon, forthcoming).

3.2. Frequency of Telecommute "Events"

Along with the number of telecommuters, the frequency of telecommute events must be assumed. Typically, the total number of telecommuting "events" is estimated assuming an average of 2 to 3 telecommute days per week per telecommuter (for all telecommuters). In projecting future telecommuting, the average number of telecommute days per week (or the proportion of full-time telecommuters) is usually assumed to increase over time. For example, the frequency of part-time home-based telecommuting events in the DOT report increased by an average of 4.4% per year. While the assumption of increased frequency is not implausible, it has not been empirically documented and, if not borne out, can lead to an inflated assessment of benefits.

While DOT assumed an increasing frequency for part-time telecommuting, others, like Finlay, have assumed a more conservative fixed frequency (i.e., part-time telecommuters telecommute two days per week). Likewise, while the DOT study assumed that full-time telecommuters telecommute five days per week, Finlay assumed full-time telecommuters telecommute only four days per week. Boghani *et al*. did not explicitly state the assumed frequency of telecommuters. Salomon notes that the "major flaw in Boghani *et al.*'s work is the fact that they fail to distinguish between full-time and part-time telecommuters" (p. 24, Salomon, forthcoming). Further, Boghani *et al*. fail to acknowledge the role of center-based telecommuting and simply treat all telecommuting as if it were home-based.

Table 8. Comparison of Assumed Telecommuting Frequency for Home-Based Telecommuters

Study	Part-Time (days per week)	Full-Time (days per week)
DOT (1993)	2.5 (average)[a]	5
DOE (1994)	(same as DOT)[b]	(same as DOT)[b]
Boghani et al. (1991)	N/A	N/A
Finlay (1991)	2	4

a. Varies from 2.0 in 1992 to 3.1 in 2002 with an average growth of 4.4% per year (unreferenced).
b. Instead of increasing the frequency of telecommuters, DOE develops a separate scenario where the distribution of different types of telecommuters is adjusted. (See p. 87, DOE, 1994.)

Current empirical evidence suggests that the average frequency for all telecommuters is less than 2 days per week. Handy and Mokhtarian (1995) found an average telecommuting frequency of 1.2 days per week during a review of eight home-based telecommuting studies which were completed in the late 1980s and early 1990s. Another study found that the average frequency of center-based telecommuting was 1.1 days per week, using data on over 10,500 telecommute occasions collected from 1991 to 1996 at 15 telecenters (Varma *et al*., 1997). The City of Los Angeles telecommuting pilot project indicates that, in general, telecommuting frequency "tends to increase over time" (p. 20, JALA, 1993). The report indicates that telecommuters with one-year of telecommuting experience average 1.05 days per week, while telecommuters with two-years of telecommuting experience average 2.0 days per week (JALA, 1993). Given that beginning telecommuters report frequencies lower than 1 day per week, we can safely assume that the overall average frequency is less than 2.0 days per week. The State of California Telecommuting Pilot Project report indicated that telecommuters averaged between 1.2 and 1.5 days per week (JALA, 1990). In general, the empirical evidence suggests that telecommuters average between 0.85 to 1.5 telecommute days per week. As a result, one can conclude that assumed average frequencies of part-time telecommuting, as well as frequencies for the aggregate telecommuting population, have been too optimistic in the past. It has been noted that the expected and desired frequency is often higher than actual telecommuting frequency (Mokhtarian *et al.*, 1996).

Rather than adjust the frequency of expected telecommuters, DOE created two scenarios based on assumed distributions of different types of telecommuters (e.g., part-time vs. full-time, and home-based vs. center-based) which, in turn, affects the average frequency for the overall telecommuting population. Using the original DOT scenario, it was assumed that the majority of growth in telecommuting would come from full-time regional telecommuting, while the DOE "alternative" scenario assumed that large growth would be experienced as full-time home-based telecommuting. While home-based telecommuting (full-time and part-time) was assumed to decrease from 99% to 44% in the DOT assumptions, DOE assumed that home-based telecommuting decreased only slightly, from 99% to 95%. (See p. 87, DOE, 1994.) Together, the distribution of different types of telecommuters (e.g., part-time vs. full-time) and the overall average frequency of the telecommuting population determine the aggregate number of "telecommute events." By increasing the aggregate number of "telecommute events," the benefits, relative to the costs, are inflated. Additionally, greater benefits can accrue from home-based telecommuting than from center-based telecommuting due to greater foregone travel, as noted in the following section.

3.3. Savings from Foregone Travel

Along with the number of telecommuters and telecommute frequency, the issue of estimating foregone travel is very important, because many of the benefits associated with telecommuting stem are the direct or indirect result of foregone travel, such as time savings, gasoline savings, or pollution savings. In general, foregone travel is estimated by using national transportation data on the average journey-to-work distance (and time). This average distance is then combined with other average estimates to quantify or monetize the transportation impacts of telecommuting, such as average fuel economy and average fuel cost or the value of travel time savings.

DOT and DOE assume that home-based telecommuters save 21.4 vehicle miles round-trip on average for each day of telecommuting, based on data from the 1990 National Personal Transportation Survey (NPTS). At the same time, it is assumed that center-based telecommuters save only 9 miles vehicle miles round-trip on average. In contrast, Boghani *et al.* does not acknowledge the possibility of center-based telecommuting and used estimates of 17.0 miles round-trip from the 1983-1984 NPTS for all estimated telecommute events.

It is also important to point out that DOT assumes that VMT increases at a rate of 3.7% per year, based on the estimated increase in VMT from 1988 to 1990. (See p. 70, DOT.) As a result, greater benefits are realized through greater foregone travel experienced through telecommuting. Except for the DOE study which addresses latent demand, all studies assume that travel savings due to telecommuting is not offset by increased non-commute travel.

Finlay (1991) used 1989 regional travel estimates together with transportation funding methods in the Greater Vancouver area to estimate project cost savings (in dollars) for each year between 1992 to 2001. Finlay cited a study conducted by the Greater Vancouver Transportation Task Force (1989) which allocated transportation infrastructure funding based on the estimated number of peak-hour commute trips. He then assumed that avoided transportation investment dollars could be computed directly from the avoided number of commute trips due to telecommuting.

Finlay's study assumes that the government would need to provide financial incentives to support telecommuting. Then, given the level of governmental support, the output consists of an estimate of the number of telecommuters. In other words, both the government incentives (costs) and the resulting capital savings (benefits) are assumed. It is not clear how the estimated number of telecommuters are "connected" mathematically to the given incentive level. To estimate the reductions in infrastructure investment, Finlay uses the number of incremental peak-hour person trips developed by the Transportation Task Force study (1989). As a result of the conversion from peak-hour person trips to infrastructure savings, any reduction in incremental trips through telecommuting allows for corresponding reductions in investment requirements.

To test the sensitivity of telecommuting to different levels of governmental incentives, three scenarios were created by Finlay. Scenario I assumes the highest level of telecommuting, thus avoids the greatest amount of infrastructure spending and produces the greatest net benefits. Scenarios II and III are identical except for the former mode of new telecommuters. (It is not clear why the distinction between Scenarios II and III is necessary given that the inputs and outputs are so similar, in contrast to Scenario I.)

Table 9. Assumptions Made in Finlay Study (1993)

	Scenario I: "Zero Traffic Growth"	Scenario II: "Reduced Traffic Growth"	Scenario III: "Zero Automobile Traffic Growth"
ASSUMED INPUTS			
Amount of Government Incentives Allocated (NPV)	$10 million	$3 million	$3 million
Incentive Allocation Timetable (all values are NPV)[a]	Begin in 1992 (year zero); $1,500 first year to begin; $800 per year thereafter to continue until 2001 (year 9).	Begin in 1994 (year two); $900 first year to begin, $600 per year thereafter to continue until 2001 (year 9).	Begin in 1994 (year two); $900 first year to begin, $600 per year thereafter to continue until 2001 (year 9).
ASSUMED OUTPUTS			
Resulting Number of New Telecommuters	49,000 by year 9	26,200 by year 9	25,200 by year 9
Former Mode of New Telecommuters	15% transit, 85% automobile	15% transit, 85% automobile	10% transit, 90% automobile

ASSUMED RESULTS			
Resulting Impacts on Transportation Infrastructure Expenditures	All transportation capacity expenditures are canceled.	All transportation infrastructure capacity expansion investments recommended for 1995-2001 are canceled.	All transportation infrastructure capacity expansion investments recommended for 1991[sic]-2001 are canceled.
Resulting Avoided Peak Hour Trips	auto: 26,336 transit: 4,647	auto: 14,081 transit: 2,485	auto: 14,341 transit: 1,593

Note: All dollars are Canadian dollars.

a. Incentives are provided per telecommuter at the net present value (NPV).

4.0. THE ECONOMIC APPROACHES

Each of the macro-scale studies included in this review utilized a basic spreadsheet approach to compute telecommuting benefits. However, it is important to note that these efforts cannot be considered to be true cost-benefit analyses since only Finlay's study took into account the "time value of money". The other reports summarize results as annual benefits with no economic discounting. For example, there is no difference between benefits reported in year 0 and those reported in year 5, other than that year 5 benefits are based on a higher number of expected telecommuters. Consequently, as Table 10 illustrates, the studies we reviewed contained little discussion of current year, planning horizon, and discount rates.

Table 10. Comparison of Economic Approaches

Study	Base Year	Horizon Year(s)	Method	Discount Rate?	Annual Growth Rate in Number of Telecommuters	Source of Annual Growth Rate
Boghani *et al.* (1991)	1988	None	undiscounted returns[a]	No	N/A	N/A
Finlay (1991)	1992	2001	net present value	10.0%	N/A	N/A
DOT (1993)	1992	2002	undiscounted annual returns	No	varies (20.2 % average)[b]	Nilles (1991)
DOE (1994)	1988	2005 2010	undiscounted annual returns	No	varies (15.5% average)[b]	variation of Nilles (1991)

a. The results from Boghani *et al.* are returns from only one year.
b. Calculated by the authors of this paper, using a compounding interest rate function, $i = (-\ln(P/F))/N$, where P is present year value, F is the future year value, and N is the time between P and F.

There are several important implications of not applying a discounting methodology to the estimated costs and benefits. Most important, not discounting implies that benefits produced today are equal in value to benefits produced in the future. Economic theory and practice, however, indicates that benefits produced today are more valuable than the benefits produced at some point in the future when discounted to a common year.

As with many long-term projects, many costs are accrued at the beginning of the project and decrease over time, while benefits continue to accrue at a constant or increasing rate over time. For example, telecommuting projects typically have high start-up costs (e.g. computer equipment) with some constant costs over time (e.g. equipment maintenance), while the benefits are expected to be relatively constant over time. As a result, failure to discount the costs and benefits would inflate the value of the benefits relative to the costs. Inflated estimates of benefits are particularly troublesome because they contribute to false expectations that may be unattainable.

5.0. MAJOR FINDINGS

Given all of the necessary assumptions and various shortcomings in methodology, the results from each study must be interpreted with caution. Further, use of different assumptions and economic techniques makes any quantitative comparison of the results difficult. Nonetheless, it is useful to examine the results obtained by each of these studies, and what they conclude about the effects of telecommuting on travel.

In this section, we have prepared a brief discussion of each individual study's findings. The major quantified or monetized results are presented with each study, and we conclude with a comparison of average benefit per telecommuter.

5.1. Overview of the Results

A general overview of the results shows that the cost and benefit elements which were included in these reports, and the extent to which each element was evaluated, vary from study to study. While some elements are monetized by the study authors, other elements can be monetized or inferred by the reader through performing a simple calculation (e.g. value of fuel savings from estimated quantities). At the same time, some studies contained monetized results which were unsupported with data or justification; these elements are typically costs which appeared to be presumed costs, and often it is not clear who would bear the burden of these costs. Many other results were quantified, but not easily monetized. These quantified results remain useful because the methodology used to obtain quantifiable results still may be valid. Finally, some elements were merely noted qualitatively and were not quantified, and others were not mentioned at all.

From Table 11, we can see that these studies do not incorporate the same range of costs, and that, in general, the costs that are included are seldom directly monetized. As noted earlier, these past studies do not claim to be cost-benefit analyses. As the table indicates, costs are generally ignored or assumed to be the responsibility of the employer. At the same time, the employer (private sector) costs associated with any requisite telecommunications infrastructure are also absent in many of these studies. The only public-sector costs might come directly from government incentives or indirectly from latent demand and/or urban sprawl.

Table 11. Consideration of Cost Elements

	Boghani *et al.* (1991)	Finlay (1991)	DOT (1993)	DOE (1994)
Public Sector				
Latent Demand	😐	😐		✧
Urban Sprawl	😐	😐		✧
Marketing/ Incentives	😐	✥	😐	😐
Lost Tax Revenue	😐	❖	✥	❖
Employer				
Telecom. Equip.	😐	❖		😐
Telecom. Software	😐	?	😐	😐
Telecom. Services	?	❖		😐
Telecom. Maint.	?	?		😐
Add'l Training	😐	✥	😐	😐
Employee				
Utilities	😐		😐	😐
Misc. Costs	😐	😐	(security)	😐

KEY: ✥ Monetized Results | ❖ Monetized Results Can Be Calculated from Quantified Results | ✧ Monetized Results Cannot Be Calculated from Quantified Results | **?** Unsupported Monetized Results | Noted, But Not Quantified | 😐 No Results Mentioned

Table 12 presents the extent to which benefits were studied. As one might expect, macro-scale public-sector benefits are clearly the focus. Public infrastructure, environmental impacts, and energy consumption are monetized or quantified by each study. Public benefits associated with economic development are traditionally more difficult to quantify and were subsequently only mentioned by most studies. Among the private sector benefits, it appears that the greatest attention is paid to work productivity benefits for the employer and commute cost savings for the employee; however it is clear that neither the employer nor the employee is the focus of these reports. It should be noted that commuter cost savings was most often quantified as foregone miles and monetized as foregone public-sector "energy consumption."

Table 12. Consideration of Benefit Elements

	Boghani *et al.* (1991)	Finlay (1991)	DOT (1993)	DOE (1994)
Public Sector				
Public Infrastructure	✥	✥	☺	✥
Environmental Impacts	✥	✧	✧	❖
Energy Consumption	✥	❖	✥	✥
Economic Development	☺			
Employer				
Work Productivity	✥	✥		
Work Absenteeism	☺	☺		☺
Parking Space Requirements.	☺	✥		☺
Office Space Requirements.	☺	✥		☺
Recruitment/ Retention	☺	☺		
Employee				
Commute Cost Savings	✧	✥	✧	☺
Misc. User Benefits	☺	❖ (insurance)	✧ (accidents)	☺

KEY: ✥ Monetized Results | ❖ Monetized Results Can Be Calculated from Quantified Results |
✧ Monetized Results Cannot Be Calculated from Quantified Results |
? Unsupported Monetized Results | Noted, But Not Quantified | ☺ No Results Mentioned

These tables indicate which of the perceived costs and benefits shown in Table 11 and Table 12 are actually addressed analytically by the studies reviewed here. The tables clearly show that, as noted in the conceptual framework, these studies focus on the public-sector perspective.

5.2. Quantified and Monetized Results

This section focuses on the quantified and monetized results presented in Table 11 and Table 12. Ranges of values in the results in the DOT and DOE reports come from an "upper bound" and a "lower bound" of telecommuting acceptance and the resulting vehicle miles saved. Additionally, the methodology is discussed in this section. Of particular interest are the telecommuting benefits to the transportation infrastructure through projections of reduced travel demand.

Transportation Implications of Telecommuting (DOT, 1993)

The DOT report provides a good discussion of potential costs and benefits, but it only quantifies public sector environmental and energy impacts, as well as estimated reductions in vehicle accidents and fatalities, from foregone travel.[5] The only monetized result coming from the DOT report is an estimate of gasoline savings. As shown in Table 13, the DOT study makes no attempt to monetize the other effects of foregone transportation demand (e.g., time saved, emissions reduced, infrastructure savings).

Table 13. Results in DOT Study (1993)

	1992	1997	2002
Saving in Vehicle-Miles Traveled (VMT) (billions)	3.7	10.0 - 12.9	17.6 - 35.1
Saving in Gallons of Gasoline (millions)	178	476 - 619	840 - 1,679
Value of Gasoline Saved (millions)	$203	$543 - $706	$958 - $1,914
Saving in Emissions (tons):			
Nitrogen Oxides (NO_x)	11,852	31,593 - 41,061	55,739 - 111,479
Hydrocarbons (HC)	14,571	38,839 - 50,468	68,524 - 137,047
Carbon Monoxide (CO)	98,753	263,229 - 342,118	464,418 - 928,836
Annual Hours Saved for Average Telecommuter	77	93	110
Total Annual Commute Hours Saved (millions)	156	444 - 577	826 - 1,652
Savings in Accidents Avoided	28,520	50,355 - 65,770	58,850 - 117,700
Savings in Lived Saved	87	231 - 300	408 - 815

Source: DOT, 1993. Note: All monetized estimates are undiscounted annual returns.

Energy, Emissions, and Social Consequences of Telecommuting (DOE, 1994)

Hoping to expand the results of the DOT report, the DOE report generated results from approximately 24 scenarios (the 16 scenarios shown in Table 2, plus eight scenarios which also adjust for increased highway capacity, increased urban sprawl, and latent demand.) The results are somewhat difficult to compare with the other studies because they are only estimated for the years 2005 and 2010, as compared to the DOT results that were estimated for each year from 1992 through 2002. Additionally, the study provides estimates of emission reductions that are derived by estimating the change in average speeds. The study does not assign a monetary value to emissions: "Because of the large uncertainties concerning the value of pollution reduction, this study emphasizes the tons reduced, rather than their value" (p. 22, DOE, 1994). However, the report presents the following table of cost estimate factors, from which the reader is able to monetize emissions reductions if desired.

Table 14. Air Pollutant Cost Estimate Factors in DOE Study (1994)

Pollutant	Damage Cost[a] (per metric ton)	Avoided Cost[b] (per metric ton)
Nitrogen Oxides (NO_x)	\$26,400	\$2,000
Carbon Monoxide (CO)	\$9,300	\$300
Hydrocarbons (HC)	\$18,600	\$3,350
Carbon Dioxide (CO_2)	\$10 to \$100	---

Source: DOE, 1994.

a. From Wang *et al.* (1993), based on California Energy Commission report for South Coast Air Basin (CEC, 1992).

b. From Greene and Duleep (1992).

The DOE report estimates that the "cumulative (undiscounted) cost savings range from \$13 billion to almost \$20 billion through 2010" based on infrastructure savings alone (p. xix, DOE, 1994). This range is attained by combining fuel savings and avoided construction savings, as these were the only results that were monetized. According to the report, increased telecommuting could result in the avoided construction of between 2,900 and 4,500 freeway lane-miles and 4,400 to 6,700 arterial lane-miles. Using cost estimates from the Federal Highway Administration (FHWA, 1991), avoided construction costs are monetized. These estimates only include construction of added-capacity infrastructure and do not include the operation, maintenance, and or repair costs.

Table 15. Estimated Avoided Transportation Infrastructure Costs Through Year 2010 in DOE Study (1994)

Highway Type	Lane-Mile Savings	Marginal Infrastructure Cost (millions per lane-mile)[a]	Total Estimated Avoided Cost (millions)
Freeways and Expressways	2,900 - 4,500	$2.5	$7,250 - $11,250
Other Principal Arterials	4,400 - 6,700	$1.3	$5,720 - $8,710
TOTAL[b]			**$12,970 - $19,960**

Source: DOE, 1994.

a. Based on FHWA estimates.

b. Note: Total results are expressed as an undiscounted total, where all results are combined through the year 2010 and expressed in 1990 dollars.

Additionally, the DOE study is the only one that attempts to quantify the effects of telecommuting given additional highway capacity, increased urban sprawl, and latent demand. Unfortunately, the results from each of these effects are not fully quantified separately. Instead, they are presented as sensitivity "factors" and are used to adjust the results from the original 16 scenarios. For example, the sensitivity factor for latent demand was found to be -_, which according to the study "implies that one DMVT [(daily vehicle-miles traveled)] removed by telecommuting in a congested urban area will be replaced by one-half a DVMT of latent demand" (p. 91, DOE, 1994). It should be noted, however, that this additional sensitivity analysis does not directly translate into foregone vehicle-miles of travel. For example, the study notes that "[the capacity expansion factor] affects delays, speeds, fuel use, and emissions" (p. 31, DOE, 1994). The parameters used in the sensitivity analysis are shown in Table 16.

Table 16. Parameters Used in Additional Sensitivity Analysis in DOE Study (1994)

Case	New Highway Capacity	Latent Demand	Urban Sprawl
High	1.0	-0.67	-1.2
Base	0.81	-0.50	-1.0
Low	0.6	-0.33	-0.8

Can Telecommunications Help Solve America's Transportation Problems? (Boghani et al., 1991)

Boghani *et al.* assume that 10 to 20 percent of all transportation activities nationwide could be substituted with telecommunications. This assumption translates directly into six million fewer automobile commuters telecommuting from home (along with three billion fewer shopping trips via teleshopping, thirteen million fewer business trips via teleconferencing, and six hundred million fewer airplane and truck delivery miles via electronic delivery). Altogether, these substitutions translate into $23 billion in annual benefits nationwide attributable to:

- $3.7 billion annually of reduced energy consumption (from 3.5 billion gallons of gasoline saved);
- $17.8 billion annually in increased work productivity (from 3.1 billion hours of "personal time" saved)[6];
- $1.2 billion annually in pollution savings (from 1.8 million tons of regulated pollutants not emitted);
- $0.5 billion annually in transportation infrastructure maintenance costs (from reduced truck and plane usage).

It is important to note here that, in general, it is difficult to make comparisons between these results and those in the other macro-scale studies, because this study takes into account foregone business, shopping, and delivery trips, along with foregone commuting trips, whereas the other studies focus on foregone commute trips. The benefits attributed to telecommuting alone are presented and compared with the results from the other studies in the next section of this paper.

As with the DOT and DOE studies, "energy savings" (i.e. fuel savings) from foregone travel was monetized. The DOE and DOT reports, however, realize that "State and Federal taxes are not true costs, but transfer payments" and subtract $0.30 per gallon from the fuel price to account for taxes. This foregone transfer payment is considered to be a cost to the government.

In their fuel savings estimates, Boghani *et al*. also attempt to account for idling fuel losses and emissions during delay due to congestion. Based on 1984 FHWA estimates of freeway delay hours in urbanized areas, 2 billion hours of urban (8 million hours of rural) congestion is estimated for 1988. Then, it is assumed that one gallon of gasoline is lost for each hour of delay. It is not clear, however, how the foregone delay from telecommuters (with work as a trip purpose) is obtained from the aggregate delay of all travelers (with an unknown trip purpose). In any event, delay adds to both fuel savings and environmental benefits attributed to telecommuting.

In contrast to the DOT and DOE studies, Boghani *et al*. attempt to monetize productivity savings. The productivity benefit is calculated through multiplying the saved time by the estimated unit value of time for the foregone activity. The average value of business trip time is appraised at $11.00 per hour, while commute time is valued at $8.88 per hour.[7] Shopping is considered a leisure activity and is not assigned a value. However, the authors note that the value of foregone commute time "can be questioned" and that "it is not clear how a few minutes saved in commuting due to congestion can be productively employed" (p. 17, Boghani *et al*.). Additionally, it is noted that commute time is usually part of the employee's personal time and that "there is no guarantee that time saved in not having to commute will be used to do productive work." (p. 17, Boghani *et al*.). Hence, the monetary value of this benefit is probably overstated.

The study also makes a distinction between urban and rural areas. The benefits for urban and rural areas were calculated separately then summed to obtain the total benefits, in part because "urban areas suffer much more from transportation problems such as congestion and pollution" (p. 20, Boghani *et al*., 1991). In contrast, the DOE study ignored rural areas entirely and focused on the 339 urban areas where "congestion is worst" and "the greatest benefits tend to occur" (p. xx, DOE, 1994).

As mentioned earlier, costs are primarily overlooked in the report. Without any documented justification, the startup costs for user equipment are estimated to be $100 billion, exclusive of maintenance costs. An additional $200 billion in startup costs is also deemed necessary for the nationwide implementation of a fiber optic telecommunication network. The authors note that this network would be able to support a 100% substitution of travel by telecommunications. The authors fail to mention, however, who is assumed to pay for this telecommunication network. In general, this study fails to distinguish between public and private costs and benefits.

Benefits, Costs, and Policy Strategies for Telecommuting in Greater Vancouver (Finlay, 1991)

In all three of Finlay's scenarios, the net regional benefit of telecommuting outweighs the costs (although it should again be emphasized that the treatment of costs is incomplete). Referring to Table 17, the net present value of the benefits ranges from $757.7 million in the "Reduced Traffic Growth" scenario to $1,768.2 million under the "Zero Traffic Growth" scenario.

Table 17. Sectoral Distribution of Net Benefits in Finlay Study (1991)

	Scenario I: "Zero Traffic Growth" (millions)	Scenario II: "Reduced Traffic Growth" (millions)	Scenario III: "Zero Automobile Traffic Growth" (millions)
Public Sector	$1,546.0	$637.1	$807.7
Employers	$85.4	$46.8	$42.6
Telecommuters	$136.8	$73.9	$70.1

Source: Finlay (1991).
Note: All results are expressed as a net present value in 1991 Canadian dollars.

In all, the public sector is the primary beneficiary of telecommuting projects under all three scenarios due to the high avoided infrastructure costs. In general, the major costs accounted for are the telecommuting incentives (borne by the public sector) and program start-up costs (borne by the employer). The net present value of transportation infrastructure cost avoidance equals $829.3 to $1,610 million. Meanwhile, the employer costs include startup expenses valued at $17.9 to $35.1 million (NPV) or $500 to $1,000 per telecommuter. Other ongoing employer costs included telecommunications ($63.2 to $125.1 million NPV or $1,500 per telecommuter every 5 years) and phone lines ($360 for analog to $900 for ISDN per telecommuter per year).

For the employer, the benefits still exceed the costs. By assuming a 9% increase in productivity from a $35,000 per year employee, a benefit of $3,150 per telecommuter per year (or $220.8 to $111.2 million NPV) is calculated for the value of increased productivity. Similarly, foregone office space savings is calculated to equal $507 to $1,140 per telecommuter per year (or, $24.8 to $12.5 million NPV). Finally, the benefits received by the set of hypothetical telecommuters totals between $70.1 million and $136.8 million from estimated commute cost savings (i.e., parking savings, transit fare cost avoidance, motor vehicle insurance cost avoidance).

While employers and employees as well as the public sector appear to benefit from this incentive policy, these scenarios remain largely theoretical. However, Finlay realizes that telecommuting would become more equitable for employers if employees or the public sector would be willing to pay for some of the costs:

> Employers receive the lowest net benefits in each project. This is partly a result of the simplifying assumption that employers pay all telecommuting startup costs and incremental communications costs. In reality, employers and telecommuters might tend to share these costs, thereby transferring part of the employees' net benefit to the employers. A more significant redistribution is possible through transferring some of the much larger public sector benefits to employers. (p 61, Finlay, 1991)

5.3. Comparison of Results

In this portion of the review, aggregate results have been disaggregated and calculated in terms of average benefit per telecommuter per year. These disaggregate values are presented for exploratory purposes to illustrate the range of values found in the literature for various benefits. This comparison is made only for the DOT, DOE, and Boghani *et al.* studies. These studies are compared because they take similar approaches, use similar aggregate data, and do not assume any government expenditures. Whenever possible results were taken directly from each report, however, many results were calculated by the authors of this report to permit as many comparisons as possible and to obtain disaggregate results that only pertained to telecommuting.[8]

While it is difficult to compare results that are presented over different study periods, a comparison is possible when all results are averaged over all telecommuters for each year to yield annual benefits per telecommuter. Because the results in the studies remain undiscounted, an average value is similar to the results that would be obtained for an average set of telecommuters in any given year. The results of this comparison are presented in Table 18.

Table 18. Comparison of Benefit Results

	Boghani *et al.* (1991)	DOT (1993)[a]	DOE (1994)[b]
VMT Savings	3,540	1,5832 - 2,097	2,047 - 2,319
Fuel Savings (gallons)	177	100 - 134	46 - 69
Fuel Cost Savings ($)	$280[c,d]	$86 - $114	$51 - $77
State & Federal Excise Tax Loss	N/A	$24 - $32	$14- $21
Avoided CO Emissions (grams)	120,415[d]	37,971 - 50,293	3,398 - 8,817
Avoided NO_x Emissions (grams)	6,054[d]	4,557 - 6,036	620 - 1,903
Avoided HC Emissions (grams)	18,166[d]	5,602 - 7,421	521 - 1,081
Avoided PM Emissions (grams)	243[d]	33 - 44	N/A
Avoided CO Emissions ($)	$64[d]	N/A	$1 - $90
Avoided NO_x Emissions ($)	$7[d]	N/A	$1 - $55
Avoided HC Emissions ($)	$23[d]	N/A	$2 - 22
Avoided PM Emissions ($)	$0[d]	N/A	$5 - $34
Time Savings (hours)[e]	174	70 - 94	5 - 7
Infrastructure Savings	$0	N/A	$45 - $69

Note: All results are per telecommuter per year, averaged for all study years.

a. Results averaged for all years 1992-2002. Ranges represent high and low average estimates.
b. Results averaged for years 2005 and 2010. Ranges represent high and low average estimates.
c. This fuel cost savings estimate *includes* state and federal excise taxes.
d. Includes fuel losses and emissions incurred during idle delay.
e. Time savings include avoided commute time only.

In general, it appears that most results are relatively close together. For example, we can see that an average telecommuter might save between 1,500 and 3,500 VMT per year while telecommuting. The disparities among emission results are representative of the uncertainty involved with estimating (and monetizing) the detrimental effects of mobile source air-pollution, as shown in Table 19 and Table 20. As noted by the DOE, “In light of mounting evidence that the current state of the art in projecting emissions in actual traffic conditions is seriously inadequate, the emissions results projected here should be viewed with caution” (p. 20, DOE, 1994).

Table 19. Values and Sources of Average Vehicle Emission Factors

	Boghani *et al.* (1991)[a] urban	Boghani *et al.* (1991)[a] rural	DOT (1993)[b] urban	DOT (1993)[b] rural	DOE (1994)	Finlay (1991)[c]
CO_2 (grams/mi)	0.00	0.00	4.71	2.44	(Based on estimated speeds)	0.00
CO (grams/mi)	25.95	11.36	29.01	8.83		46.85
NO_x (grams/mi)	1.59	1.54	3.02	2.46		3.04
HC (grams/mi)	4.39	3.32	--	--		5.76
PM (grams/mi)	0.07	0.06	--	--		0.11
CO_2 idle (grams/hr)	0	0	(none)	(none)	(none)	(none)
CO idle (grams/hr)	297	297				
NO_x idle (grams/hr)	3.8	3.8				
HC idle (grams/hr)	26.3	26.3				
PM idle (grams/hr)	0.01	0.01				

Note: All emission factors are grams per mile, except idle emissions which are in grams per hour.
a. Source: unreferenced.
b. Source: MOBILE 4.1 (EPA, ?)
c. Source: Greater Vancouver Regional District Pollution Control (1988).

Table 20. Values and Sources of Emission Values

	Boghani *et al.* (1991)[a] (urban)	Boghani *et al.* (1991)[a] (rural)	DOE (1993) (damage)[b]	DOE (1993) (control)[c]
CO_2 (\$/ton)	0.00	0.00	10 to 100	0.00
CO (\$/ton)	502.58	0.00	9,300.00	300.00
NO_x (\$/ton)	1,251.91	0.00	26,400.00	2,000.00
HC (\$/ton)	1,251.91	0.00	18,600.00	0.00
PM (\$/ton)	0.00	0.00	0	0.00

a. Converted from $/gram. Source: unreferenced.
b. Source: Wang *et al.*, 1993.
c. Source: Greene and Duleep, 1992.

It is important to note that the DOE report indicates lower fuel savings per telecommuter per year than the DOT report, even though the DOE report indicates that the average telecommuter saved more VMT. In both cases, fuel savings estimates were not calculated by the authors of this report, but were obtained directly from the reports. The difference appears to lie in different assumptions about average fuel economies.[9] In general, it is clear that the that the Boghani *et al.* report takes the most optimistic stance as all of their basic results are significantly higher than those of DOT or DOE.

6.0. CONCLUSION

In this paper, we have outlined a conceptual framework by which cost-benefit analyses of telecommuting should be conducted. We noted that an economic evaluation of telecommuting should ideally begin by identifying the scale, perspective, and scope of the study, and by establishing the base case conditions. Additionally, it was noted that an economic approach with appropriate discounting methods must be selected before the costs and benefits can be computed. Once all of the analysis data and computational parameters have been defined, the actual benefits and costs can be computed and evaluated.

This paper also took a critical look at four macro-scale economic evaluations of telecommuting. The evaluation begins by recognizing that there are certain critical parameters and major assumptions that a complete economic evaluation of telecommuting should explicitly address, specifically:

- the current number of telecommuters
- the frequency of telecommute "events" by each telecommuter
- the number of vehicle miles of travel (or travel time) foregone by telecommuting
- the assumed growth in the number of telecommuters
- the assumed average discount rate
- the allocation of costs among each sector (public, employer, employee)

Additionally, this review noted that studies should have sensitivity analysis conducted around key expected parameters, such as assumed growth in the number of telecommuters and future discount rates. This is particularly important when the critical assumptions are assumed and not based on empirical work. Moreover, it is important to recognize the shortcomings in the literature and the tendency for assumptions to "snowball," as noted by Salomon (forthcoming).

While the use of a spreadsheet model with macro-scale estimates appears to be a commonly accepted and practiced approach to estimate the potential benefits of telecommuting, this approach has not been without its shortcomings. Specifically, a failure to account for most costs and a failure to fully monetize most results is characteristic of the studies conducted to date. Telecommuting can be properly evaluated only after these two shortcomings are addressed.

While it is believed that telecommuting is still growing, the fact remains that it is difficult to gauge future levels of telecommuting and its impacts on travel. While past studies clearly suggest that telecommuting has the potential to provide benefits to all sectors of the economy, the distribution of costs across these sectors is still not clear. As a result, continued research must be done to clarify the costs and benefits associated with telecommuting. Macro-scale studies should be combined with micro-scale studies to fully evaluate the economic impact that telecommuting would have on all sectors, because while the public sector may be the recipient of many of the benefits, telecommuting must be feasible and economically beneficial to both the employer and the employees to spur greater levels of adoption and substitution for travel. In other words, a complete cost-benefit analysis must include private sector costs and benefits. Above all, more empirical research of telecommuting economics and collection on cost-benefit data remains necessary.

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[1] In *The Information Economy*, Porat divided the workforce into four sectors: agriculture, industry (manufacturing), service, and information (Porat, 1977). The information worker sector was later used by Nilles to estimate number of potential telecommuters, as information workers were thought to be the group of occupations most suitable for telecommuting.

[2] Ratio of Information Workers in the Labor Force, $IW/LF = 1/[1.5 + e^{(76.683 - 0.03914 * t)}]$
Ratio of Telecommuters in the Information Work Force, $TC/IW = 1/[1.5 + e^{(424.70 - 0.21145 * t)}]$
(Ratio of Telecommuters in the Labor Force, $TC/LF = IW/LF * TC/IW$)
Number of Telecommuters in year t, $TC = LF * IW/LF * TC/IW$.

According to the DOE report, "The values 1.5 in the denominators of these curves were inserted by assumption to force the shares to approach a limit of 2/3 as t grows large" (p. 85, DOE, 1994).

[3] Note that the number of commuters in the labor force noted by Boghani *et al*. may represent only a fraction of the total labor force. It may be the number of *employed* workers and may exclude, among others, the unemployed or home-based business workers. According to the NPTS, there were approximately 96.6 million "workers" in 1980. (See p. 2-2, NPTS, 1993.) At the same time, the Bureau of Labor Statistics indicates that there were approximately 99.3 million "employed civilians" in 1980. (See p. 393, U.S. Bureau of Labor Statistics, 1995.) This distinction is important when making comparisons with other macro-scale studies which derive its telecommuting population from the full labor force (e.g., DOT, 1993).

[4] Boghani *et al*. assume that the rural labor force has "4% less information workers . . . due to the decreased number of white-collar jobs" (p.25, Boghani *et al*., 1993).

[5] According to the DOT study, "telecommuters reduce their risk of injury and death by reducing the amount of time they spend in ruch-hour traffic" (p. 81, DOT, 1993).

[6] Note that productivity gains account for 77% of the total benefits.

[7] These values were based on a report by the Texas Transportation Institute which approximated the 1985 value of time for passenger car drivers to be $8.00 per hour. The 1985 rate of $8.00 per hour was then inflated by Boghani *et al.* to 1988 prices to obtain a rate of $8.88 per hour. The value of time for business trips appears to be arbitrarily chosen by Boghani *et al.* to "be approximately 25% greater, since business travelers often travel during business hours (when their time is worth more than during leisure hours)" (p. 35, Boghani *et al.*, 1991).

[8] It should be noted that these calculations were particularly important for the results from the Boghani *et al.* study because most of their aggregate results do not pertain only to telecommuting and include an evaluation of teleshopping, teleconferencing, and electronic data transfer. For example, the $0.5 billion savings in infrastructure costs was not attributed to reduced passenger vehicle usage, but instead was the result of reduced truck and plane traffic from foregone business travel and freight demand.

[9] While the DOT study uses an average fuel economy of 20.92 mpg during its entire study period, the DOE study uses an average fuel economy of 18.0 mpg in 2005 and 20.5 mpg in 2010. Additionally, DOT assumes fuel costs of $1.14/gal, while DOE assumes fuel costs of $1.40/gal in 2005 and $1.55/gal. in 2010. In both cases, $0.30/gal is subtracted as public excise tax losses taxes.