Title

Telecommuting, Residential Location, and Commute Distance Traveled: Evidence from State of California Employees

Authors
Mokhtarian, Patricia L.
Collantes, Gustavo O.
Gertz, Carsten

Publication Date
2003-06-01

TELECOMMUTING, RESIDENTIAL LOCATION, AND COMMUTE DISTANCE TRAVELED: EVIDENCE FROM STATE OF CALIFORNIA EMPLOYEES

by

Patricia L. Mokhtarian
Department of Civil and Environmental Engineering
and
Institute of Transportation Studies
University of California, Davis
Davis, CA 95616
voice: (530) 752-7062
fax: (530) 752-7872
e-mail: plmokhtarian@ucdavis.edu

Gustavo O. Collantes
Institute of Transportation Studies
University of California, Davis
Davis, CA 95616
voice: (530) 754-7421
fax: (530) 752-6572
e-mail: gcollantes@ucdavis.edu

and

Carsten Gertz
Technical University of Hamburg-Harburg
European Center for Transportation and Logistics
Research unit 1-10
D-21071 Hamburg
Germany
phone: + 49 / 40 / 42878-3518
fax: + 49 / 40 / 42878-2728
e-mail: gertz@tu-harburg.de

June 2003

TELECOMMUTING, RESIDENTIAL LOCATION, AND COMMUTE DISTANCE TRAVELED: EVIDENCE FROM STATE OF CALIFORNIA EMPLOYEES

Patricia L. Mokhtarian, Gustavo O. Collantes, and Carsten Gertz

ABSTRACT

This study analyzes retrospective data on telecommuting engagement and residential and job location changes over a ten-year period, from 218 employees (62 current telecommuters, 35 former telecommuters, and 121 people who had never telecommuted) of six California state government agencies that had actively participated in the well-known pilot program of 1988-90. We compare estimates of the total commute person-miles traveled of telecommuters and non-telecommuters, on a quarterly basis.

Key findings include: (a) One-way commute distances are higher for telecommuters than for non-telecommuters, consistent with prior empirical evidence and with expectation. (b) Average telecommuting frequency declines over time. Several explanations are proposed, but cannot be properly tested with these data. (c) The first two findings notwithstanding, the average quarterly per-capita total commute distances are generally lower for telecommuters than for non-telecommuters, indicating that they telecommute often enough to more than compensate for their longer one-way commutes.

We cannot say from these results whether the ability to telecommute is itself prompting individuals to move farther away, or whether telecommuting is simply more attractive to people who already live farther from work for other reasons. Even if the first case is true, however, and telecommuting is the "problem", it also appears to be the solution, i.e. enabling people to achieve a desired but more distant residential location without negative environmental impacts.

1. INTRODUCTION

The potential transportation impacts of telecommuting, defined here as salaried employees working from home instead of commuting to the usual workplace at the usual time, have been the subject of considerable research. A number of empirical studies on the transportation impacts of telecommuting (see, e.g., Hamer, *et al.*, 1991; Mokhtarian, *et al.*, 1995) are unanimous in finding substantial net reductions in vehicle miles traveled by telecommuters, on days that they telecommute, for as long as they are telecommuting (although it has also been suggested that the net impacts on a systemwide level will be rather modest, e.g. Mokhtarian, 1998). Because of its apparent transportation benefit, telecommuting has found its way into numerous public policy statements promoting trip reduction strategies – such as the United States bill H.R. 4475 (Sec. 359), signed into law on October 23, 2000, which states that "each executive agency [of the Federal government] shall establish a policy under which eligible employees of the agency may participate in telecommuting to the maximum extent possible without diminished employee performance".

However, all of the empirical studies to date have focused on short-term impacts, within one to two years of the adoption of telecommuting by the individual and/or the organization. In contrast, almost nothing is known about the long-term effects of telecommuting on activities such as residential location. A number of researchers (e.g., Janelle, 1986) have raised the issue that the ability to telecommute may prompt workers to move farther away from their jobs to cheaper or higher-amenity residential locations, resulting in a longer but less frequent commute. The total commute distance traveled in such cases may actually be higher after telecommuting than before. If such cases are quite common, then the degree to which telecommuting is promoted as a travel-reduction strategy should be re-examined. Hence, we need information on the extent and nature of the impact of telecommuting on residential location in order to inform transportation policies relating to telecommuting.

Several studies have explored the potential impacts of telecommuting on residential location and urban form from a theoretical economic perspective. Higano and Orishimo (1990), Lund and Mokhtarian (1994), Kim (1997), and Safirova (2001) assume a monocentric city, with all workplaces located either in the central business district (CBD) or (through telecommuting to the CBD workplace) at home. Stough and Paelinck (1996) acknowledge the presence of employment in edge cities, while Shen (2000) allows for a more general distribution of employment. Not surprisingly, all of these studies find that telecommuting can lead to further decentralization of the city.

None of these theoretical approaches has been empirically validated, however, and empirical evidence with respect to impacts of telecommuting on residential location remains scanty. The potential for substantial relocation impacts, at least for a fraction of telecommuters, is apparent: in one early study of San Diego, California telecommuters, Mokhtarian (1997) found a small proportion of respondents (two out of 34, or 6%) reporting that the ability to telecommute was prompting consideration of moves that would double or even quadruple their one-way commute length. Similarly, in his evaluation of the two-year State of California pilot project, Nilles (1991) found that 6% (four out of 67) of the telecommuters studied indicated that they had moved or were considering moving at least 45 miles farther from work since they began to telecommute.

However, no significant differences in number or length of work trips were found between actual moves of the telecommuters and those of a control group, suggesting that telecommuting *per se* was not prompting any more decentralization than that due to the various forces already at work on non-telecommuters and telecommuters alike.

On the other hand, using the nationwide, large-sample Work Schedules supplement from the 1997 Current Population Study, Ellen and Hempstead (2002) found that telecommuters were actually more likely to live in large urban areas, and less likely to live in rural areas, than were non-telecommuters. These results were strongest for so-called “hard-core” telecommuters (defined as those reporting working at home more than 20 hours a week) – i.e. those who might be expected to have the greatest location flexibility. However, their study did not speak directly to commute length nor to the role of telecommuting in residential location decisions.

Of course, even if longer one-way commutes do result from telecommuting in some specific instances, the net change in commuting could still be negative if (1) at the individual level, the worker telecommutes often enough to compensate for the longer commute, and/or (2) at the aggregate level, the increases for some are outweighed by the reductions for others. Thus, it is important not to focus exclusively on specific adverse cases, but rather to examine the net or average impact across a pool of telecommuters, as we do in the current study.

One obvious reason for the lack of empirical studies of this relevant question is that residential location decisions take place over a longer time scale than the one- or two-year durations of most telecommuting pilot programs and their evaluations. A study would ideally need to follow telecommuters and otherwise comparable non-telecommuters over a period of perhaps 5-10 years in order to garner a large enough sample of moves from which to draw statistically robust conclusions, and few funding agencies (not to mention researchers) are willing to commit the necessary resources for that long a period of time.

To help at least partially bridge this gap in knowledge, the present study takes a more practical approach. Specifically, we conducted a single cross-sectional survey of current, former, and non-telecommuters, but asked retrospectively about their residential and job relocations, as well as their telecommuting engagement, over the preceding 10 years. Although such an approach is obviously subject to recall errors, we believe that residential and job changes are sufficiently rare and important events for most people, that their timing can be remembered with relative accuracy, particularly to within a given quarter of the year, which is the scale on which we captured the information. (Certainly, any number of demographic studies have been conducted using a similar method and based on the same assumption). Telecommuting engagement is probably less important to many people (and may change more often), and hence may be remembered less accurately, than residential or job changes. Nevertheless, respondents did not appear to have much trouble providing the requested information (there was relatively little apparently missing or unclear data), and we believe that despite inevitable imperfections in the data, analyzing the patterns they represent can offer useful insight into the complex relationships of interest. In any event, to our knowledge this study represents the first attempt to empirically study relationships among telecommuting, residential location, and total commute travel over a 10-year period.

A key challenge of analyzing specifically the impact of telecommuting on residential location is the proper attribution of causality. People move closer to or farther from work all the time, for reasons having nothing to do with telecommuting or even commuting. Given general trends toward urban decentralization in the US, and some evidence that commute lengths are increasing over time (e.g., based on the Nationwide Personal Transportation Survey, Hu and Young, 1999 report that average commute lengths increased by 36% from 1983 to 1995, from 8.54 to 11.63 miles), a simple finding that telecommuters are moving farther away from work on average is not at all conclusive evidence that telecommuting should actually be "blamed" for such moves. Directly asking telecommuters whether that is the case is unreliable (although still worth doing), since respondents to a survey on telecommuting are likely to put undue emphasis on the role of telecommuting in their self-reported behavior. Comparing moves of telecommuters to those of an otherwise similar non-telecommuting group offers more rigorous evidence, but it can be difficult to identify a control group that is sufficiently similar to the telecommuters on key variables of interest.

In any case it should be kept in mind that telecommuters would not move farther from work simply *because* they are able to telecommute. Rather, in the worst case telecommuting simply makes possible a move that is desired for other reasons – to accommodate household needs, to obtain a larger and/or cheaper home or lot, to be near scenic locations or other amenities, and so on. Thus, telecommuting can be at worst viewed as a facilitator, not an actual driver, of such moves (see, e.g., de Sola Pool, 1980; Mokhtarian, 1993; Nijkamp and Salomon, 1989). Nevertheless, to the extent telecommuting is responsible for releasing a constraint that was preventing further decentralization (and to the extent such decentralization is considered socially undesirable), telecommuting is arguably as culpable as if it were a driver in its own right. In reality, of course, it could be rather difficult to disentangle the relative roles of drivers and facilitators, to determine the extent to which one factor could be singled out as being responsible for the move, as opposed to a number of factors acting in concert, with indivisible impact.

In view of these caveats with respect to attributing causality, the main focus of the present study is on the joint impact of telecommuting, residential location, and job location on transportation – specifically, commute travel. One immediate virtue of this focus is that it begs the question of causality entirely. We need not determine whether a relocation was an effect of telecommuting, a cause of it, or had any relationship to it at all. We simply compare the commute distance traveled of telecommuters and non-telecommuters. From the transportation planning perspective, this is arguably the key issue. Even if telecommuting does motivate some individuals to relocate far from work, if their commute frequency declines so much that their travel is still reduced, or if increases in their travel are outweighed by decreases in travel for other telecommuters, then policymakers may still be appropriately inclined to promote it.

The organization of the remainder of this paper is as follows. In Section 2 we describe the empirical context and the available data, and in Section 3 we discuss the definitions of two important variables in the study: commute PMT and quarterly telecommuter status. In Sections 4, 5, and 6 we present the main results associated with each of the three key variables analyzed here: one-way commute length, telecommuting frequency, and commute person-miles traveled (PMT), which is a function of the first two. Section 7 offers a summary and discussion of the findings.

2. EMPIRICAL SETTING AND AVAILABLE DATA

In 1988-90, the State of California conducted one of the best-known early telecommuting pilot programs for its employees, involving around 150 telecommuters in 14 state government agencies (JALA Assoc., 1990; Kitamura *et al*., 1990). In the intervening years, telecommuting has continued to thrive in some areas of the state government, offering a valuable opportunity for evaluating the long-term relationships of interest in this study.

To that end, we designed a 16-page self-administered survey, and in November 1998 distributed it to a sample of employees of six California state agencies that have kept active telecommuting programs since the original pilot program in 1988. These six agencies are: California Energy Commission, Department of Personnel Administration, Franchise Tax Board, California Youth Authority, Department of Motor Vehicles, and Department of Social Services.

Respondents were recruited through an initial e-mail message broadcast to key divisions or groups within each agency. The message stressed that non-telecommuters and former telecommuters, as well as current telecommuters, were needed for the study. As an incentive to participate, respondents to the survey were entered into a drawing for cash prizes of $250, $150, and $100. Because of the broadcast nature of the recruitment message, a response rate is impossible to determine. Such a figure would be largely irrelevant in any case, since the recruitment approach was designed to enrich the sample with telecommuters. In view of this sampling bias, the sample does not purport to be representative, at least certainly not in the proportion of telecommuters it contains. For some of the analysis reported in Section 5, we weight respondents to more accurately reflect the proportions of telecommuters and non-telecommuters in the population as a whole (see the Appendix for details of the weighting procedure).

Independent of the representativeness of the proportion of telecommuters in the sample is the question of whether the telecommuters we do have are representative of the population of telecommuters. Data on even the number of telecommuters are of limited reliability, and data on their demographic and other characteristics are even sketchier. Thus, we are not able to speak definitively to the representativeness of the telecommuters in our sample. We speculate, however, that over the 10-year retrospective period covered by the survey, the sample of telecommuters may be less representative the farther back in time we go. That is, we suspect that from our sample, collected entirely in 1998, the subset identified as telecommuting in Fall 1988 could be less representative of telecommuters at that point in time than is the subset identified as telecommuting in Summer 1998. Specifically, we speculate that people telecommuting 10 years ago who responded to a survey a decade later might have had more extreme circumstances than the typical telecommuter of that time. For example, they may have had longer commute distances, higher telecommuting frequencies, and longer telecommuting durations (perhaps even still telecommuting 10 years later). The idea is that such a committed telecommuter would be more likely to respond to a 1998 telecommuting survey than the "dilettante" who tried it for a couple of months in 1988 and never did it since then, whereas that same dilettante would have been more inclined to respond had a similar survey been conducted in 1988.

Thus, the apparent temporal trends in telecommuting and commuting activity seen later in this paper should be viewed with some caution. It is unknown the extent to which such trends are genuine, or an artifact of the sampling bias. Nevertheless, the most important conclusion of this study, that telecommuters do not have greater total commute travel than non-telecommuters, holds true even if only the most recent time periods are the main focus. Another potential source of unrepresentativeness is the fact that the sample contains only state employees. Their attitudes and behavior may differ systematically from those of private sector employees, although no particular hypotheses with respect to the current study present themselves.

Our database contains 218 cases for which commute person-miles traveled can be computed in least at one of the 41 quarters studied: 62 people who were currently telecommuting when the data were collected, 35 individuals who had telecommuted in previous quarters but not in the last (thus totaling 97 cases who had ever telecommuted), and 121 people who had never telecommuted during the study period.

In a data set this small, one or a few unusual cases can substantially skew the results. Thus, it was important to identify and remove outliers from the sample before proceeding with the analysis. Outliers were identified based on the commute person-miles traveled (the estimation of which is described in Section 3). For each respondent, quarters with commute person-miles traveled in excess of three standard deviations from the mean, and relatively isolated from the rest of the observations for that quarter, were considered potential outliers and examined one by one. Note that this determination was based on total commute PMT, not on one-way commute length. A few respondents had one-way commute lengths that would be considered outliers by a similar definition, but their telecommuting frequency was sufficiently high to render their total PMT not extraordinarily large. Such cases are precisely a focus of interest for telecommuting, and should not be excluded on the basis of a high one-way commute length alone. This process resulted in the exclusion of a maximum of three outliers in any given quarter, with most quarters having no outliers. Only the extreme quarters were removed for a given respondent, not the entire case.

The self-administered written survey contained two 10-year timelines, each divided into 3-month periods. On the first timeline, current and former regular telecommuters indicated all the periods of time during which they telecommuted regularly, the frequency with which they telecommuted during each of those periods, and reasons for quitting or changing frequency in each case. (Regular telecommuting was defined as "at least two days a month on average, for at least three consecutive months"). On the second timeline, all respondents indicated all job and residential relocations that took place during the 10-year span, and for each move indicated the commute distance, time, and mode that resulted (as well as the values of those variables at the beginning of the 10-year period). As described further in Section 3, these responses permitted calculation of total commute distance traveled for each respondent in each quarter, based on the one-way commute length and telecommuting frequency in effect for that quarter.

In addition, the survey collected data on attitudes toward telecommuting, reasons for and other characteristics of the three most recent residential and two most recent job relocations, impacts of telecommuting on relocations and conversely, impacts of telecommuting on frequency and destination for a number of trip purposes, general transportation-related choices, job characteristics, home characteristics, and standard demographic characteristics. The current study focuses on the information available from the two timelines; preliminary analysis of other parts of the survey can be found in Gertz and Mokhtarian (1999). To convey the nature of the sample, descriptive statistics for key demographic variables are shown in Table 1. Two thirds of the respondents are female, the median age is 44, and median household size is 3. The current and former telecommuters in this sample have higher educations and incomes, on average, than do the non-telecommuters, perhaps indicating possession of jobs requiring greater skill and having greater autonomy, that hence are more conducive to telecommuting. Somewhat in contrast to the finding of Ellen and Hempstead (2002), telecommuters, especially current ones, are also far more likely than never-telecommuters to live in the countryside, medium-size city, or suburb, and less likely to live in a large city. The implications of these differences for the analysis are discussed in Section 4.

[Table 1 goes about here]

3. DEFINITIONS OF COMMUTE PMT AND TELECOMMUTER STATUS

As indicated earlier, our focus in this paper is on the joint impact of residential/job location and telecommuting on distance traveled. While our data contain some information on travel behavior for purposes other than going to work, it is only for the commute that we have measures quantified in miles for the entire 10-year period of study. Thus, our analysis concentrates on calculating commute person-miles traveled at each quarter, and comparing those measures between telecommuters and non-telecommuters (commute vehicle-miles traveled are also analyzed in Collantes and Mokhtarian, 2003; the substantive results from that analysis are similar to those reported here for PMT). This is another limitation of this study – it is possible, e.g., that telecommuters reduce their *commute* travel even after potentially adverse residential relocations, but that their *work-related and/or non-work* travel increases, perhaps due in part to their new more decentralized, lower density (even exurban or rural), perhaps more auto-oriented, residential location. Previous empirical studies in the US and the Netherlands have not found substantial increases in non-work travel by telecommuters or even their household members (Mokhtarian, 1998; Hamer, *et al.*, 1991), but again, such studies are almost exclusively short-term.

To analyze commute travel with the present data set requires some simplifying assumptions, which we now describe. The two-way mean daily commute person-miles traveled (PMT) by person i in quarter q is estimated as

$$DPMT_{iq} = 2D_{iq}\left(1 - \frac{tcf_{iq}}{wd_q}\right),$$

where D_{iq} is the reported one-way commute length for person i in quarter q, wd_q is the number of working days that apply to California state employees in quarter q (number of weekdays less the number of official state holidays), and tcf_{iq} is the telecommuting frequency for person i in quarter q. That is, the daily round-trip commute distance for an individual is deflated by a factor equal to the proportion of working days on which the commute is made.

This is only an approximation of the actual commute PMT, as it does not account for any of the possible departures from this theoretical amount of commuting. For example, this formula would overestimate the real PMT for work schedules like part-time or compressed work week, and it would underestimate the actual PMT for people who commute more than once a day, who commute on the weekends as well as during the week, or who sometimes only telecommute partial days (perhaps to avoid the peak period) but still make the commute. It does not account for varying numbers of personal leave days taken by the respondents. Trip chaining behavior would also induce deviations from this approximation of PMT, although that is a more complex phenomenon. One possible scenario would be that a person makes certain additional trips only on the way to or from work, in which case part of the commute distance should perhaps be "charged" to those other trips, and our approximation overestimates the actual commute PMT. Another scenario would be that on telecommuting days a person chooses alternative destinations for the trips that would normally be made on the way to or from work, in which case the net effect on our approximation cannot be evaluated. Finally, there will be some round-off error due to the use of the coarse unit of quarters. If completely random, those round-off errors will cancel out. There may be a bias toward overstating the amount of remembered telecommuting (that is, marking a quarter as one in which telecommuting occurred, even though it only occurred for less than half the three-month period), but this could be counteracted by entirely forgotten episodes of telecommuting. On the whole, we believe our simple formula is a reasonable first-order approximation to commute PMT, and its uniform application across the sample should offer a fairly accurate estimate of changes over time and differences across subgroups.

Until now, we have categorized each respondent into one of three groups: current telecommuter, former telecommuter, or non-telecommuter. Since we will be analyzing commute PMT on a quarter-by-quarter basis, however, it is important to refine our telecommuter status classification, and in particular to classify each respondent on a quarter-by-quarter basis. Thus, for each quarter, respondents are categorized as telecommuter (TCer) or non-telecommuter (NTCer), depending on whether they report engagement in telecommuting for that quarter or not. Thus, those previously classified as current or former telecommuters will be TCers in some quarters and NTCers in others, while the never-telecommuters will remain NTCers throughout the study period. Other definitions of TCer are potentially of interest (for example, allowing "spillover" of TCer status into adjacent non-TCing quarters, on the premise that relationships between TCing activity and commuting or relocation could also spill over into adjacent quarters), but are not pursued in this paper for the sake of brevity.

4. ONE-WAY COMMUTE LENGTH

Figure 1 shows the average one-way commute lengths for telecommuters and non-telecommuters, on a quarter-by-quarter basis. These averages are larger than for the U.S. as a whole. The Nationwide Personal Travel Survey reports nationwide average commute trip lengths of 10.65 and 11.63 miles for the years 1990 and 1995 respectively, compared to 15-18 miles for our sample in the same years. The longer commutes in our sample are not surprising in view of its concentration of urban middle-class-and-higher white collar professionals and managers, who would be expected to have longer commutes than the average for the workforce as a whole.

The most obvious aspect of the figure, however, is that telecommuters have higher mean commute lengths than non-telecommuters across the board, with the difference being statistically significant (at the 0.05 level or better) for the 18 quarters whose markers are enlarged in the figure. This is consistent with the observation made in Section 2, that telecommuters' (current) residential locations are far more likely to lie in peripheral areas of a region than in a large city. Since we also noted in Section 2 that the ever-telecommuters (former and current) in our sample tended to have higher incomes than the never-telecommuters, and since income is well-known to be positively associated with commute length, it is legitimate to ask whether those never-telecommuters constitute an appropriate control group for this study. That is, to what extent is the observed difference in Figure 1 due to the income differential rather than to telecommuting status per se?

[Figure 1 goes about here]

In response, several comments are pertinent. (1) Income measures are only available for the final quarter, whereas in Figure 1, telecommuting status is determined on a quarter-by-quarter basis. Thus, the 97 ever-telecommuters of Table 1 will often be classified as non-telecommuters in Figure 1 (in fact, that is the case for about 2/3 of their possible telecommuting quarters). In those cases, the higher incomes of currently non-telecommuting ever-telecommuters will mix with the lower incomes of the never-telecommuters (both constituting the non-telecommuters category for a given quarter), and the role of income in the observed differences between telecommuters and non-telecommuters is diluted accordingly.

(2) In the sample as a whole, the correlation between income and one-way commute length at the final quarter is rather weak: 0.09 (p-value 0.20) directly, and 0.12 (p-value 0.07) when controlling for education. Education, incidentally, is significantly *negatively* correlated with commute length in this sample: -0.15 (p-value 0.03). Thus, the effects of education and income on commute length partially counteract each other, at least here. These results suggest that the differences in commute length between telecommuters and non-telecommuters are probably not due to the income (and education) differences shown in Table 1, but to other factors.

(3) To the extent that these sample differences reflect genuine differences between the *populations* of telecommuters and non-telecommuters, Figure 1 arguably constitutes a fair comparison of the (relatively) typical telecommuter to the (relatively) typical non-telecommuter, while acknowledging that those two groups differ in some systematic ways. In fact, other evidence suggests that telecommuters indeed tend to have higher incomes and more education than non-telecommuters (Pratt, 1993; Drucker and Khattak, 2000), and have longer commutes (Mokhtarian, *et al*., 1995; Gareis, 2003). In at least some of these studies, the data are not taken from a small-sample study of telecommuting, which would be more susceptible to bias, but from large-sample general-purpose data sets that can be considered reasonably representative of the population as a whole. Both results are behaviorally plausible: telecommuters are more likely to have professional, higher-autonomy jobs that come with higher-than-average incomes (as noted in Section 2), and having a longer commute is one potential important motivation to telecommute (as noted throughout this paper). Thus, the differences seen here are not inconsistent with logical expectations and with objective evidence.

(4) Given that we find in Section 6 that telecommuters' *total* commute PMT is already less than or equal to that of non-telecommuters', if they started out with one-way commute lengths closer to those of non-telecommuters, the result (all else equal) would be even more favorable to telecommuting. Thus, if the difference seen in Figure 1 *is* a bias, it is not one that favors telecommuting; if anything, quite the opposite.

(5) Nevertheless, it is of interest to try and control to some extent for the role of income in the observed differences. To do that, we selectively removed lower-income never-telecommuters from the sample so as to make the income distributions of ever- and never-telecommuters more similar (specifically, we removed 22 never-telecommuters from the $15,000 – 34,999 category shown in Table 1, including xxx who indicated that they were unable to telecommute, so that the remaining never-telecommuters more nearly resemble could-be-telecommuters. A chi-squared test then found no significant difference in the income distributions of that reduced group and the ever-telecommuters). Figure 1b xxx shows the outcome for one-way commute length: that of the telecommuters does not change, while xxx

Returning to the discussion of Figure 1, the spikes for the telecommuting mean in the third and fourth quarters of 1989 and the third quarter of 1990 are dramatic, but reflect the effect of one extreme case on the small group of telecommuters. For example, one case reported a one-way commute distance of 229 miles for the third and fourth quarters of 1989, when the sample numbers of telecommuters were 12 and 13 respectively. Despite the large differences in the mean for each group, the standard deviations for the telecommuters are so large in those quarters that the differences are not statistically significant. Although the extreme cases in these three quarters are clearly outliers with respect to one-way commute distance, their total commute PMT amounts do not qualify as outliers (due to their telecommuting frequency), and so as discussed in Section 2, they were retained for this analysis. The differences in mean distance for the last few quarters are also striking. Although for most of the study period the non-telecommuters' commute lengths are slowly increasing, in the last six quarters the non-telecommuters' mean commute lengths actually decline while the telecommuters' rise.

Overall (but especially toward the end of the study period, when telecommuting adoption is at its maximum for these data), two processes are probably occurring simultaneously in the sample: (1) People who already live or eventually move farther from work for conventional reasons, over time become more inclined to adopt telecommuting, in which case telecommuting could be viewed as a beneficial strategy to reduce commute-related VMT. (2) As telecommuting becomes available to them, relocating farther from work becomes more attractive (or less costly), in which case telecommuting could be viewed as a malignant incentive for increased decentralization of residences.

Whether cause or effect, it is clear that in this sample (as elsewhere), telecommuters have higher mean one-way commute lengths than non-telecommuters. The question naturally arises as to whether that difference will translate into a significantly higher total commute PMT for telecommuters, which would cast a shadow on the expectations for telecommuting to contribute to a sustainable transportation system. The answer to this question will be related to the way commute distance and telecommuting frequency interact: will telecommuters telecommute frequently enough to outweigh their longer one-way commute distances? To provide insight into this relationship, the following section explores patterns of telecommuting frequency.

5. TELECOMMUTING FREQUENCY

Figure 2 shows the mean telecommuting frequencies for the telecommuting subsample in each quarter, together with the sizes of those subsamples. The clear decaying trend exhibited by the curve, converging to a frequency of about 1.5 times/week, must be interpreted with caution. We hypothesize four possible reasons for this decay: the first one is essentially that it is an artifact of the sampling procedure, while the latter three represent genuine potential behavioral mechanisms. In general, it needs to be kept in mind that the sampling strategy used resulted in obtaining a sizeable subsample of telecommuters *at the last quarter*. That is, we did not sample telecommuters independently at each quarter. One should not then think of the sample size curve as necessarily representative of the evolution in the number of telecommuters in the agencies surveyed (although part of the increase with time in the number of adopters should in fact be attributed to the diffusion of the new work arrangement). A quarter-by-quarter sampling would have, most likely, rendered the increasing trend shown by the sample size curve less steep (i.e., we would have captured more people telecommuting 10 years ago if we had sampled them 10 years ago, than by sampling them now). The trend exhibited by the frequency curve is probably influenced in turn by effects of the sampling procedure.

[Figure 2 goes about here]

Specifically, our first hypothesis for the decay in mean telecommuting frequency over time is twofold: (a) the latter quarters contain a higher, more representative, proportion of short-term telecommuters, having lower frequencies, with the result of pulling the average frequency down; and (b) the longer-term ever-telecommuters that *are* in the sample are less likely to *remember* low-frequency episodes of telecommuting that occurred several years in the past, compared to more recent low-frequency episodes. The combined effect of those sampling and response biases, if true, would be that while higher-frequency telecommuters are represented throughout the study period, lower-frequency telecommuters are underrepresented in the early quarters. Under this hypothesis, if samples had been taken quarter by quarter, a more realistic representation of lower frequency telecommuters in the early quarters would have rendered the curve flatter, closer to the convergent value of the frequency.

However, there are three legitimate reasons why, even if the sample is representative at each quarter, we might see a decaying trend in mean telecommuting frequency. Thus, our second hypothesis is that for a given individual, telecommuting frequency may decline over time due to factors such as a fading interest or competing demands. This hypothesis is difficult to test with the current sample, since individuals generally reported average telecommuting frequency at the episode level, stretching over any number of quarters, which would mask any decline in frequency across the duration of the episode. However, Mokhtarian and Meenakshisundaram (2001) found clear evidence of such a pattern through analyzing the actual incidence of telecommuting occasions over a six-month period for a sample of 115 users of telecommuting centers throughout California.

Our third hypothesis emerges from the observation that telecommuting frequencies decline not only with time, but also with the number of telecommuters. This suggests that later adopters of telecommuting might be diluting the higher frequencies of the early adopters, i.e. that the same factors motivating individuals to adopt telecommuting earlier rather than later might also motivate them to telecommute more often. The second and third hypotheses are not mutually exclusive, even for the same individual. In this sample, the effects of the first and third hypotheses are completely confounded. That is, while we can confirm that earlier adopters in our sample telecommute more frequently (as attested by regressing initial and average telecommuting frequencies against quarter of first adoption; detailed results available in Collantes and Mokhtarian, 2003), we do not know the extent to which this is a genuine behavioral relationship, or a consequence of our sampling procedure.

A fourth hypothesis, similar in rationale to the third, is that longer-duration telecommuters have a higher than average telecommuting frequency, independently of whether adopting earlier or later (and, again, still potentially decaying over time as well). Specifically, the rationale is that the same factors motivating individuals to persist in telecommuting for longer periods rather than quitting, might also motivate them to telecommute more often. However, there does not appear to be a rigorous way to test this hypothesis with these data, since most telecommuters (62 of 97) were still telecommuting at the end of the study period and hence their durations are censored. For example, we may only have observed someone to be telecommuting for one quarter at the time the data were collected, but her actual duration, extending beyond the data collection point, could be far longer than that. Since duration is unknown for such censored cases, we are unable in those cases to correlate it with telecommuting frequency.

To summarize, there are solid reasons for believing that aggregate average telecommuting frequencies do decline over time, but the trend shown in Figure 2 is probably exaggerated to an unknown degree by the sampling bias.

6. COMMUTE PERSON-MILES TRAVELED

As described in Section 3, total commute PMT is a function of the one-way commute length and the frequency with which the commute is made. Having examined these two constituents in Sections 4 and 5 respectively, we now put them together and analyze their combined impact on commute PMT. In Section 6.1, we simply compare the average daily commute PMT for TCers and NTCers on a quarter-by-quarter basis. In Section 6.2, we pool the data while weighting TCers and NTCers to reflect their relative estimated proportions in the population, and thereby quantify the extent to which TCers' contribution to overall PMT is disproportionate.

6.1 Comparison of Commute PMT for TCers and NTCers

Figure 3 plots the mean daily per-capita commute PMT for TCers and NTCers, on a quarterly basis. The more erratic nature of the plot for TCers, compared to NTCers, corresponds to the strong fluctuations in mean one-way commute lengths for telecommuters shown in Figure 1. That figure illuminates why the mean daily per capita PMT for telecommuters dips in the first and second quarters of 1992, despite the fact that especially the first of those quarters corresponds to a low in mean telecommuting frequency, as shown in Figure 2: the reduction in telecommuting frequency is more than compensated for by the reduction in one-way commute length. Those first two plus the fourth quarters in 1992 are the only quarters for which there is a statistically significant difference in daily per-capita commute PMT between telecommuters and non-telecommuters, as indicated by larger markers in both series for those three quarters. A number of additional quarters showed marginally significant differences. For all but five of the 41 quarters, however, including any quarter where a significant or marginally significant difference in the per-capita PMT is registered, the lower value corresponds to the telecommuting segment. This is of course an encouraging result, given that telecommuting as a transportation management tool is aimed partly at reducing PMT. It is all the more dramatic in view of the fact, as shown in Figure 1 and discussed in Section 4, that the mean one-way commute lengths of telecommuters exceed those of non-telecommuters in *every* quarter. Clearly, telecommuting is being used to compensate for an above-average one-way commute distance, and in fact so far has more than compensated for it.

[Figure 3 goes about here]

However, the trend in the final few quarters of the study period is worrisome: the combination of the widening gap in the one-way commute length shown in Figure 2, and the falling or flat telecommuting frequency shown in Figure 3, results in daily per-capita commute PMTs that are nearly identical for the two groups. In two of the last three quarters, telecommuters' commute PMT is slightly higher than non-telecommuters', although the difference is statistically negligible. If the per-capita commute PMT of the two groups continues to stay essentially equal, that can still be considered a positive result of telecommuting. However, if the gap in one-way commute length continues to widen (i.e. if, over time, telecommuters are more and more disproportionately those living farther and farther from work, relative to non-telecommuters) while telecommuting frequencies have stabilized, telecommuters' per-capita commute PMT will soon exceed that of non-telecommuters. However, it should still be reiterated that telecommuting may not be *causing* an increased decentralization – it may be that those moving (or already living) farther from work for other reasons are more likely to adopt telecommuting to at least mitigate, if not eliminate, the additional commute travel involved. Further, we are not able to tell the extent to which the observed result is an artifact of the sampling bias discussed in Section 2. For reasons presented there, it may be that the last few quarters are the most representative of the true comparison between telecommuters and non-telecommuters.

6.2 Telecommuters' Contribution to Overall PMT

Figure 3 illustrates that per-capita commute PMT is generally lower for telecommuters compared to non-telecommuters. It is of interest to factor the per-capita measures up to the aggregate level, to compare the telecommuters' contributions to overall commute PMT to their proportions in the population at each quarter. For example, if telecommuters constitute 6% of the workforce in a given quarter, what percent of total commute PMT does their travel constitute? To conduct this analysis, we apply the weighting scheme detailed in the Appendix.

Figure 4 compares the proportion of total commute PMT done by telecommuters with their proportions in the workforce on a quarterly basis, and plots the ratio of those two proportions as well. As we knew from the per-capita numbers shown in Figure 3, telecommuters' proportion of total commute PMT is lower than their proportion in the workforce for all but five quarters, but Figure 4 quantifies this more explicitly. PropTCerPMT is the proportion of commuting PMT accounted for by the weighted sample of telecommuters. Its value ranges from 0.009 in the first quarter, to 0.120 in the last quarter. PropTCers is the ratio of the number of telecommuters to the total workforce in the United States (linear interpolation of yearly data, as shown in the Appendix). This variable has a value of 0.020 in the first quarter, and of 0.123 in the last (that is, telecommuters ranged from 2% to 12% of the workforce over the study period). Analysis of the ratio plotted in the figure shows that, on average, telecommuters' contribution to commute PMT is only 85% of their proportion in the workforce. Again, however, in the last three quarters telecommuters are contributing to total commute PMT almost exactly in proportion to their representation in the workforce.

[Figure 4 goes about here]

Having seen that telecommuters' commute PMT is lower than non-telecommuters', it is of interest to examine what their commute PMT *would be* if they were not telecommuting but all else remained unchanged. In Figure 5 we present the quarterly proportion of total weighted PMT actually done by the telecommuters in our sample, together with the proportion of the corresponding weighted PMT they would do if they were not telecommuting. PropHypoTCer PMT is the proportion of the total commuting PMT that the same weighted sample of telecommuters would have if they were commuting to work five times a week. This proportion is 0.025 at the first quarter and 0.172 at the last quarter. Figure 5 shows that the actual weighted PMT of telecommuters is substantially lower than the PMT they potentially would have, if they were not telecommuting. On average the hypothetical PMT proportion is 48% higher than telecommuters' proportion in the workforce, with a high of 187% in the third quarter of 1989 and a low of 12% in the fourth quarter of 1992, and concluding the 10-year study period at 41% higher. This suggests that telecommuters, although living farther from work than non-telecommuters on average as shown in Figure 1, seem to adjust their PMT through telecommuting frequencies so that, in the aggregate, their amount of commute travel approximately matches their expected share of commute PMT. In fact, their resulting commute is, overall, less than would be predicted by their share of the workforce. However, the hypothetical nature of these results must be stressed. If these individuals were not able to telecommute, we do not know how many would relocate so as to reduce their commute PMT.

[Figure 5]

7. SUMMARY AND CONCLUSIONS

In this study we investigate 10-year retrospective data on the telecommuting engagement and residential/job changes of a sample of 216 employees of six California state agencies that have operated telework programs since 1988. The focus of the study is, through the analyses of telecommuting behavior and one-way commute length, to analyze the joint impact of those decisions on person-miles traveled (PMT). Although the limitations of this study prevent it from offering definitive answers, it still provides some provocative initial answers to these important research and policy questions.

Key findings include: (a) One-way commute distances are higher for telecommuters than for non-telecommuters, consistent with prior empirical evidence and with expectation. (b) Average telecommuting frequency declines over time. This again is behaviorally plausible and consistent with prior independent results, but the trend seen here may be exaggerated due to the sampling bias in this study. (c) The first two findings notwithstanding, the average quarterly per-capita total commute distances are generally lower for telecommuters than for non-telecommuters, indicating that they telecommute often enough to more than compensate for their longer one-way commutes.

Weighting the sample to represent telecommuters proportionally to their presence in the national workforce, we find that on average, the proportion of telecommuters' contribution to commute PMT is only 85% of their proportion in the workforce. In the last three quarters of the study, telecommuters are contributing to total commute PMT almost exactly in proportion to their representation in the workforce. Yet because of their longer one-way commutes, if telecommuters were not telecommuting but all else were held constant, their contribution to commute PMT would be 48% higher than their proportion in the workforce on average – 41% higher in the final quarter of the study period.

It should be emphasized again that in this paper we do not argue for any particular direction of causality. That is, we are not able, on the basis of the analyses presented here, to discern whether longer commute distances encourage telecommuting, or conversely, whether the adoption of telecommuting facilitates residential relocations farther away from the workplace. As a corollary, we are unable to assess the desirability of telecommuting from this specific standpoint. While each direction of causality is possibly true for different people (or for the same people at different times), it is quite possible that the benign effects of telecommuting are dominant. The argument for this is that given a residential location, the adoption of telecommuting is virtually costless, while moving to a more distant location is a costly decision that usually involves a number of drives with a bigger weight than the possibility to telecommute. However, confirming this speculation would require an investigation into the role of telecommuting in relocation decisions that is beyond the scope of this paper.

Regardless of the direction of causality, however, the net outcome of decisions on telecommuting and residential/job location appears to be positive with respect to commute PMT. These results offer support for the continued promotion of telecommuting as a transportation demand management strategy, while also underlining the need for continued investigation into the complex relationships in which it plays a role.

ACKNOWLEDGEMENTS

The initial survey design, data collection, and analysis for this project were funded by BMW AG and involved the able assistance of Vikram Thairani. We also acknowledge with appreciation the assistance of the State of California staff who facilitated the data collection effort, including David Fleming, Department of Personnel Administration; Nan Powers, California Energy Commission; Sue Teranishi, Franchise Tax Board; Elaine Scanlon, Department of Motor Vehicles; Dorothy Carter, California Youth Authority; and Tom Benson, Department of Social Services. The current analysis was funded by the University of California Transportation Center. The valuable advice of Ilan Salomon and constructive comments of Elizabeth Deakin are gratefully acknowledged.

REFERENCES

Collantes, Gustavo O. and Patricia L. Mokhtarian (2003) *Telecommuting and Residential Location: Relationships with Commute Distance Traveled for State of California Workers*. Research Report No. UCD-ITS-RR-03-xx, Institute of Transportation Studies, University of California, Davis, August.

de Sola Pool, Ithiel (1980) Communications technology and land use. *Annals of the American Academy of Political and Social Science* **451**,1-12.

Drucker, Joshua and Asad J. Khattak (2000) Propensity to work from home: Modeling results from the 1995 Nationwide Personal Transportation Survey. *Transportation Research Record* **1706**,108-117.

Economic Report of the President (2001) United States Government Printing Office: Washington, DC.

Ellen, Ingrid Gould and Katherine Hempstead (2002) Telecommuting and the demand for urban living: a preliminary look at white-collar workers. *Urban Studies*, **39**(4): 749-766.

Gareis, Karsten (2003) Home-based versus mobile telework: The interrelationship between different types of telework. Chapter 13 in Paul Jackson and Birger Rapp, eds. *Organisation and Work Beyond 2000*. Berlin: Springer-Verlag, 171-185.

Gertz, Carsten and Patricia L. Mokhtarian (1999) Endbericht: *Die Langfristigen Auswirkungen von Telearbeit auf das Verkehrsverhalten und Umzugsentscheidungen* (The Long-Term Effects of Telecommuting on Travel Behavior and Residential Location). Report to BMW AG, Verkehrskonzepte Munchen, Germany, July (in German).

Hamer, Rebecca, Eric Kroes, and Harry van Ooststroom (1991) Teleworking in the Netherlands: An evaluation of changes in travel behaviour. *Transportation* **18**, 365-382.

Higano, Yoshiro and Isao Orishimo (1990) Impact of spatially separated work places on urban residential location, consumption and time allocation. *Papers of the Regional Science Association* **68**, 9-21.

Hu, Patricia S. and Jennifer R. Young (1999) *Summary of Travel Trends: 1995 Nationwide Personal Transportation Survey*. US Department of Transportation Federal Highway Administration, Washington, DC, December.

JALA Associates (1990). *The California Telecommuting Pilot Project Final Report*. Department of General Services, State of California. North Highlands, CA. June.

Janelle, Donald G. (1986) Metropolitan expansion and the communications - transportation trade-off. In Susan Hanson, ed. *The Geography of Urban Transportation*. New York: The Guilford Press, 357-385.

Kim, Sun-Wung (1997) *Impacts of Telecommuting Policies on Urban Spatial Structure and the Environment: Home-based and Center-based Telecommuting*. PhD Dissertation, Regional Science, University of Pennsylvania.

Kitamura, Ryuichi, Jack Nilles, David Fleming, and Patrick Conroy (1990). Telecommuting as a transportation planning measure: Initial results of State of California pilot project. *Transportation Research Record* **1285**, 98-104.

Lund, Jay R. and Patricia L. Mokhtarian (1994) Telecommuting and residential location: Theory and implications for commute travel in monocentric metropolis. *Transportation Research Record* **1463**, 10-14.

Mokhtarian, Patricia L. (1993) The travel and urban form implications of telecommunications technology. Presented at the Federal Highway Administration / Lincoln Institute of Land Policy workshop on Metropolitan America in Transition: Implications for Land Use and Transportation Planning. Washington DC, September 9-10. Paper available from the author.

Mokhtarian, Patricia L. (1997) The transportation impacts of telecommuting: Recent empirical findings. Chapter 4 in Peter Stopher and Martin Lee-Gosselin, eds., *Understanding Travel Behaviour in an Era of Change*. Oxford, UK: Elsevier (Pergamon Press), pp. 91-106.

Mokhtarian, Patricia L. (1998) A synthetic approach to estimating the impacts of telecommuting on travel. *Urban Studies* **35(2)**, 215-241.

Mokhtarian, Patricia L. and Ravikumar Meenakshisundaram (2001) Patterns of telecommuting engagement and frequency: A cluster analysis of telecenter users. *Prometheus* **20(1)**, 21-37.

Mokhtarian, Patricia L., Susan L. Handy and Ilan Salomon (1995) Methodological issues in the estimation of travel, energy, and air quality impacts of telecommuting. *Transportation Research A* **29A(4)**, 283-302.

Mokhtarian, Patricia L., Ilan Salomon, and Sangho Choo (2003) Measuring the measurable: Data and measurement issues in transportation, with telecommuting as a case study. Submitted to *Social Science Research*, manuscript available from the authors.

Nijkamp, Peter and Ilan Salomon (1989) Future spatial impacts of telecommunications. *Transportation Planning and Technology* **13(4)**, 275-287.

Nilles, Jack M. (1991) Telecommuting and urban sprawl: Mitigator or inciter? *Transportation* **18(4)**, 411-432.

Pratt, Joanne H. (1993) *Myths and Realities of Working at Home: Characteristics of Homebased Business Owners and Telecommuters.* Prepared for the United States Small Business Association under contract no. SBA-6647-OA-91. Summary and ordering information available at http://www.sba.gov/ADVO/research/rs134.html, accessed May 30, 2003.

Safirova, Elena (2001) A model of a residential economy with telecommuting. Manuscript available from the author at safirova@rff.org.

Shen, Qing (2000) New telecommunications and residential location flexibility. *Environment and Planning A* **32(8)**, 1445-1463.

Stough, Roger R. and Jean Paelinck (1996) Substitution and complementary effects of information on regional travel and location behavior. *Proceedings of the workshop on New International Perspectives on Telework*, Brunel University, West London, England, July 29-August2, pp. 380-397.

Table 1: Key Characteristics of the Sample

	Total sample	Current telecommuters	Former telecommuters	Never-Telecommuters
Categorical/ordinal variables: Frequency (%)				
Gender				
Female	150 (68.8)	45 (72.6)	26 (74.3)	79 (65.3)
Male	68 (31.2)	17 (27.4)	9 (25.7)	42 (34.7)
Total	218 (100.0)	62 (100.0)	35 (100.0)	121 (100.0)
Education				
Some grade or high school	2 (.9)	- (-)	1 (2.9)	1 (.8)
High school graduate	3 (1.4)	- (-)	- (-)	3 (2.5)
Some college	86 (39.4)	20 (32.3)	14 (40.0)	51 (43.0)
Four-year college degree	62 (28.4)	22 (35.5)	6 (17.1)	34 (28.1)
Some graduate school	32 (14.7)	10 (16.1)	5 (14.3)	17 (14.0)
Completed graduate degree	31 (14.2)	10 (16.1)	8 (22.9)	13 (10.7)
Total	216 (99.1)	62 (100.0)	34 (97.1)	120 (99.2)
Annual personal income				
Less than $15,000	3 (1.4)	1 (1.6)	- (-)	2 (1.7)
$15,000 to 34,999	40 (18.3)	5 (8.1)	4 (11.4)	31 (25.6)
$35,000 to 54,999	93 (42.7)	27 (43.5)	21 (60.0)	45 (37.2)
$55,000 to 74,999	49 (22.5)	18 (29.0)	3 (8.6)	28 (23.1)
$75,000 to 94,999	18 (8.3)	5 (8.1)	4 (11.4)	9 (7.4)
$95,000 or more	15 (6.9)	6 (9.7)	3 (8.6)	6 (5.0)
Total	218 (100.0)	62 (100.0)	35 (100.0)	121 (100.0)
Residential area type				
Large city	91 (41.7)	21 (33.9)	15 (42.9)	55 (45.5)
Suburb of large city	59 (27.1)	18 (29.0)	11 (31.4)	30 (24.8)
Medium-size city	25 (11.5)	10 (16.1)	5 (14.3)	10 (8.3)
Small city	17 (7.8)	2 (3.2)	3 (8.6)	12 (9.9)
Town or village	6 (2.8)	1 (1.6)	- (-)	5 (4.1)
Countryside	18 (8.3)	9 (14.5)	1 (2.9)	8 (6.6)
Total	216 (99.1)	61 (98.4)	35 (100.0)	120 (99.2)
Continuous variables: Mean (s.d., N)				
Age	43.2 (8.7, 217)	43.2 (8.6, 62)	44.7 (8.9, 35)	42.8 (8.8, 120)
Household size	2.8 (1.4, 218)	2.7 (1.3, 62)	3.0 (1.1, 35)	2.9 (1.4, 121)

Figure 1: Quarterly Average One-Way Commute Lengths of Telecommuters and Non-Telecommuters

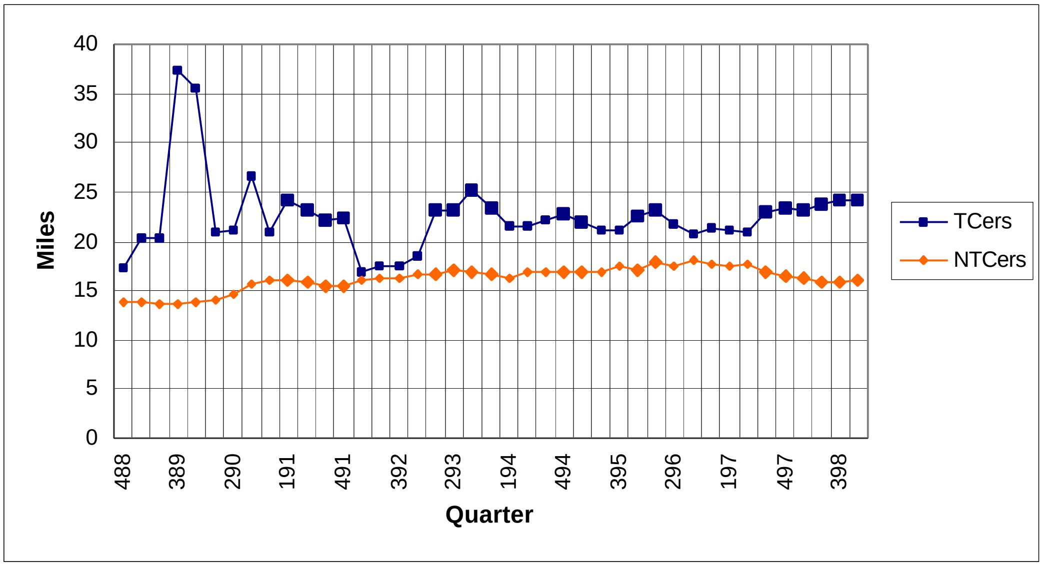


Figure 2: Quarterly Average Telecommuting Frequencies

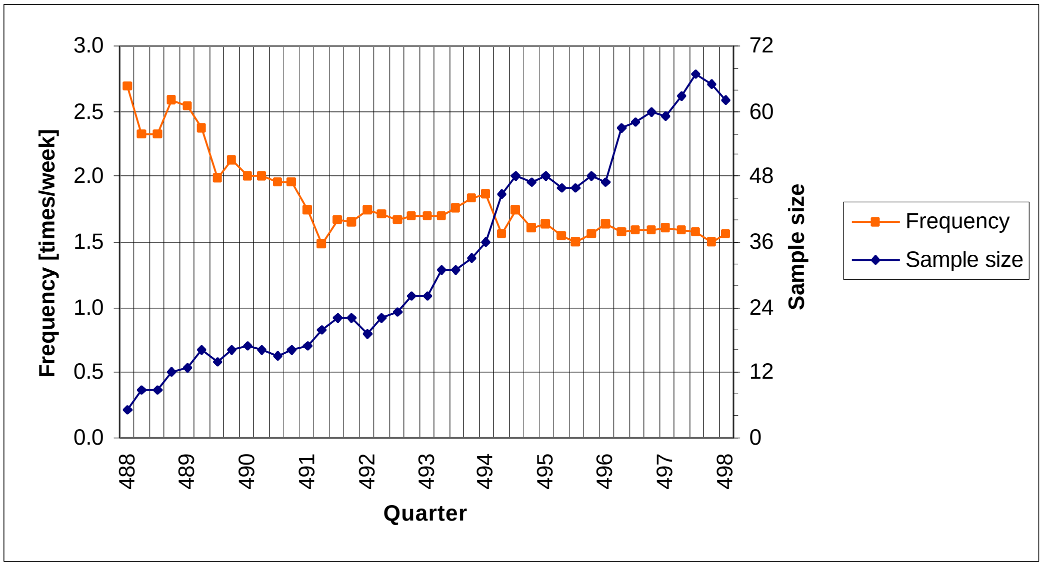


Figure 3: Mean Daily Per-Capita Commute Person-Miles Traveled for Telecommuters and Non-Telecommuters

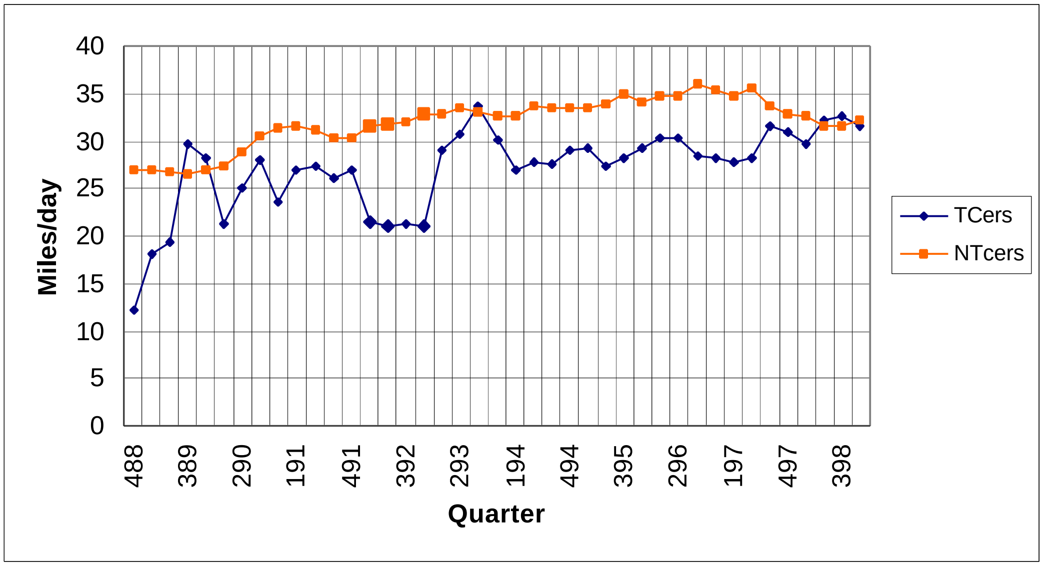


Figure 4: Proportion of Total Commute PMT Due to Telecommuters, Relative to their Proportion in the Workforce

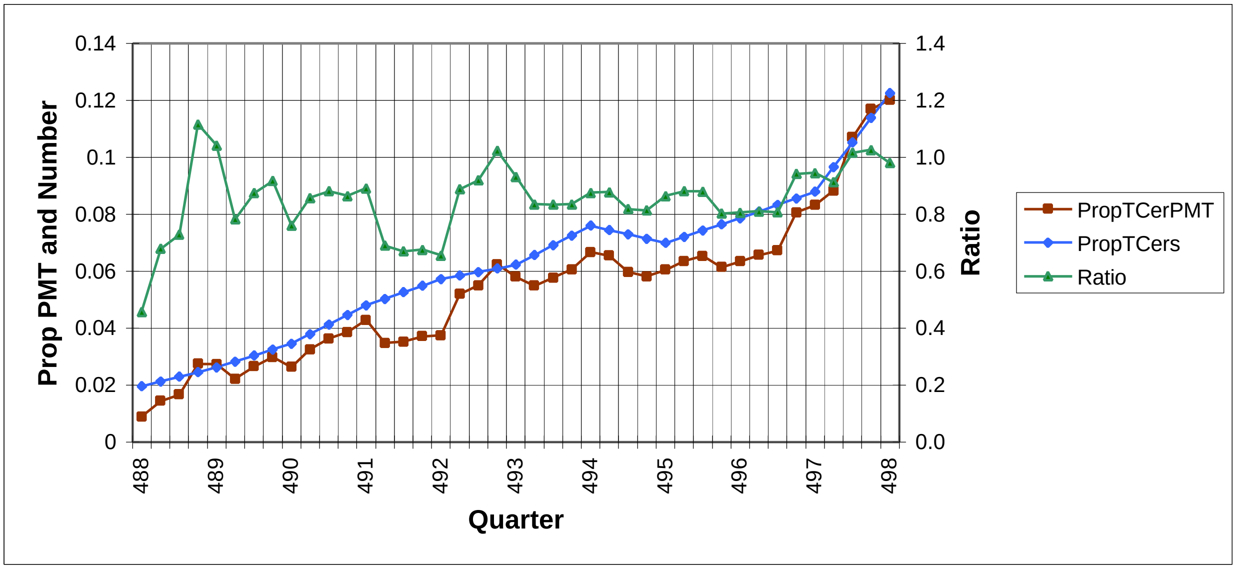
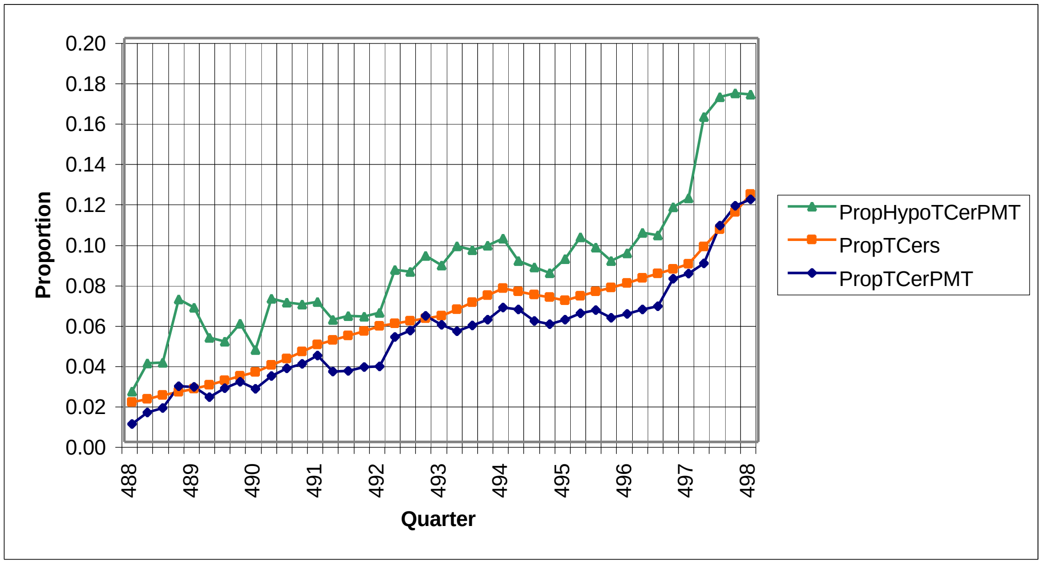


Figure 5: Comparison of Actual and Hypothetical (If Not Telecommuting) PMT of Telecommuters, Relative to their Workforce Proportion



APPENDIX: WEIGHTING THE SAMPLE

We wish to weight each observation according to the proportion of telecommuters and non-telecommuters in the workforce as a whole. For the denominator of this proportion, the number of workers, we used data on the total non-agricultural workforce in the U.S., obtained from the Economic Report to the President (2001). Our source for the number of telecommuters (the numerator) was a series of annual nationwide surveys conducted by the same individual (Thomas Miller) at several different market research firms across time (LINK Resources from 1988 through 1993, FIND/SVP from 1994 through 1997, and Cyber Dialogue for 1998). Data at the national level were used since information on the number of telecommuters for the period under study was not available at a finer level of disaggregation, and particularly not for the same geographic area of this study. Although there are concerns about the quality of these data, and in particular a likelihood that they overestimate the number of telecommuters (see Mokhtarian *et al.*, 2003 for a detailed discussion), they are the only sources documenting telecommuting trends on an annual basis. And for our purposes, an overestimation of the number of telecommuters may not be as serious as it would be for other purposes. In determining how the proportion of telecommuters' commute PMT compares to their population proportion, if the latter proportion is overestimated, then so will be the former (because the weights given to telecommuters' PMT are based on their estimated proportions in the population), and the ratio of the two may be relatively accurate.

The ratio of population telecommuters to the total (non-agricultural) working population, available on a yearly basis, was linearly interpolated so as to yield a value for each quarter in the study period. For our sample to be representative of the population proportion of telecommuters, these ratios, at each quarter, would need to equal the corresponding ratios of sample telecommuters to total sample workers. Thus, the weights applied to each telecommuter in each quarter are the ratio of the population proportion of telecommuters to their sample proportion, and similarly for non-telecommuters. In our sample the weights for telecommuters are less than one for every quarter, indicating that the contribution of the oversampled telecommuters is dampened while that of the undersampled non-telecommuters is inflated by the application of the weights.

These weights are only approximations for at least three reasons. First, the nationwide estimates of telecommuters are subject to a number of caveats, as mentioned earlier. Second, our sample is entirely drawn from State of California employees of a few agencies, concentrated in the state capital of Sacramento, and is unlikely to be representative of the entire U.S. workforce. For example, telecommuting probably occurs at higher rates among State of California employees than in the U.S. workforce as a whole, due to the supportive policy statements issued by state government over the years. However, as indicated earlier, there are no reliable data on telecommuting engagement at a finer geographical level. Third, although we correct (to the extent possible) for the overrepresentation of telecommuters in the sample, we have no way of correcting for the possible response bias toward more extreme telecommuters discussed in Section 2. Thus, we applied the unweighted reported telecommuting frequencies and one-way commute lengths to the weighted sample of telecommuters in calculating telecommuters' commute PMT. However, the speculated response biases could partly counteract each other when it comes to estimating the commute PMT of telecommuters: our sample might reflect higher-than-average telecommuting frequencies for the early years of the study period, but if it also reflects higher-than-average one-way commute lengths, the quarterly commute PMT exhibited by the sample telecommuters might be close to typical for telecommuters of that period. Again, however, this can only be considered possible, with an unknown degree of likelihood. Despite these caveats, we believe that applying even approximate weights to our sample will result in useful insights not possible to obtain from the unweighted sample alone.

Table A presents the values of the variables involved at each quarter. The sample numbers of telecommuters and non-telecommuters reported in the table are those for whom all the data necessary to compute the person-miles traveled in the quarter of interest are available. Thus, for example, in the first quarter there are 17 cases whose missing data preclude the calculation of their PMT.

Table A: Weighted Distribution of TCers and Non-TCers in Each Quarter

Quarter	Population workforce (millions)	Population tele-commuters (millions)	Interpolated ratio of population tele-commuters to population workforce	Sample number of tele-commuters	Sample number of non tele-commuters	Weighted sample number of tele-commuters	Weighted sample number of non-tele-commuters
4/1988	111.800	2.2	0.020	5	194	3.916	195.084
1/1989	114.142	3.0	0.021	9	189	4.223	193.777
2/1989			0.023	9	190	4.573	194.427
3/1989			0.025	12	188	4.926	195.074
4/1989			0.026	13	187	5.257	194.743
1/1990	115.570	4.0	0.028	16	185	5.701	195.299
2/1990			0.030	14	188	6.150	195.850
3/1990			0.033	16	185	6.538	194.462
4/1990			0.035	17	183	6.922	193.078
1/1991	114.449	5.5	0.038	16	187	7.708	195.292
2/1991			0.041	15	188	8.391	194.609
3/1991			0.045	16	187	9.073	193.927
4/1991			0.048	17	187	9.803	194.197
1/1992	115.245	6.6	0.050	20	186	10.374	195.626
2/1992			0.053	22	184	10.849	195.151
3/1992			0.055	22	185	11.378	195.622
4/1992			0.057	19	188	11.855	195.145
1/1993	117.144	7.3	0.059	22	186	12.174	195.826
2/1993			0.060	23	186	12.497	196.503
3/1993			0.061	26	183	12.760	196.240
4/1993			0.062	26	183	13.024	195.976
1/1994	119.651	9.1	0.066	31	180	13.873	197.127
2/1994			0.069	31	180	14.598	196.402
3/1994			0.073	33	175	15.105	192.895
4/1994			0.076	36	172	15.819	192.181
1/1995	121.460	8.5	0.075	45	164	15.578	193.422
2/1995			0.073	48	163	15.407	195.593
3/1995			0.072	47	163	15.015	194.985
4/1995			0.070	48	164	14.836	197.164
1/1996	123.264	9.7	0.072	46	165	15.226	195.774
2/1996			0.074	47	166	15.834	197.166
3/1996			0.077	49	164	16.298	196.702
4/1996			0.079	48	165	16.762	196.238
1/1997	126.159	11.1	0.081	58	155	17.256	195.744
2/1997			0.083	58	156	17.834	196.166
3/1997			0.086	60	155	18.417	196.583
4/1997			0.088	59	156	18.917	196.083
1/1998	128.085	15.7	0.097	63	152	20.776	194.224
2/1998			0.105	67	148	22.635	192.365
3/1998			0.114	65	149	24.380	189.620
4/1998			0.123	62	152	26.231	187.769

LIST OF TABLES AND FIGURES