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1. INTRODUCTION

Telecommuting, or teleworking as it is more commonly known in Europe, is viewed (among other things) as a strategy for reducing commute-related vehicle miles traveled (VMT). An exact, universal definition of telecommuting is not agreed upon (see, e.g., Mokhtarian *et al*., 2003). In broad terms, it can be understood as the utilization of information and telecommunications technologies in order to work from a location other than the regular work place. Section 14200 of the California Government Code, relating to the California State Employee Telecommuting Program, specifies: "As used in this chapter, 'telecommuting' means the partial or total substitution of computers or telecommunication technologies, or both, for the commute to work by employees residing in California" (http://www.dpa.ca.gov/, accessed on November 12, 2002). The survey on which the present study is based used the following definition: "By teleworking (or 'telecommuting'), we mean: working from home (or a nearby center) instead of going to your normal workplace at the usual time. It can be formal (e.g. involving a signed agreement) or informal. Don't count overtime work at home, a home-based business, or required work at a field location as teleworking".

The potential demand for telecommuting has probably not been fully realized yet, for a number of reasons. One is the difficulty of office managers to adapt to a new working paradigm, whereby connectivity is achieved virtually. A second important reason is security: classified or proprietary information sometimes cannot be transferred electronically with sufficient warranty that it will not be intercepted. Additional reasons include the lack of appeal of telecommuting work schemes for some people whose jobs are suitable for telecommuting (for example because they value the social interaction at the workplace), and technical constraints such as, for example, the lack of personal computers at home, or the expense or lack of availability of a high-speed broadband data link to the office from home.

These factors have also prevented telecommuting from being fully exploited as a traffic demand management (TDM) tool. An additional barrier to the more effective promotion of telecommuting as TDM policy is that the impacts of telecommuting on travel and energy demand are not fully understood. With respect to those impacts, one fundamental unanswered research question is: what are the implications of telecommuting adoption for residential location? Telecommuting provides commuters with a tool to alleviate their overall commute cost (monetary, time and/or perceptual), thus reducing their incentives to choose residential locations closer to their work place. In the aggregate, this effect may theoretically constitute an influence toward urban sprawl. To the extent this is the case, the effectiveness of telecommuting as a travel reduction tool is called into question and it may become counterproductive to promote it as public policy from that perspective. Thus, it is important to obtain more insight into the interplay between telecommuting and residential location.

The choice of the residential location is usually the output of complex, heterogeneous, decision making processes where many factors beside transportation costs are taken into consideration. Nevertheless, the characteristics of the commute can certainly play a significant, sometimes even decisive, role in location decisions. Conversely, of course, residential location has a significant impact on transportation, and it is important to analyze this relationship as well in the context of telecommuting.

This study helps fill this research gap by analyzing data from 218 employees of the State of California, collected through a self-administered survey distributed in 1998. Among other information, the data contain retrospective responses regarding telecommuting engagement and frequency, commute distances, residential relocations and job relocations for the period from 1988 to 1998, on a quarter-by-quarter basis.

A previous descriptive analysis of these data (Gertz and Mokhtarian, 1999) qualitatively explored the impact of telecommuting on residential location. Future analysis will address this issue in greater depth. The key challenge of such an analysis is the proper attribution of causality. As noted, people move closer to and farther from work all the time, for reasons having nothing to do with commuting or telecommuting. Although the data collection methodology was designed to help rule out competing explanations for location changes (e.g. having a non-telecommuting comparison group, directly asking about the role that telecommuting played in the (re)location decision), none of the mechanisms employed could provide the perfect, airtight approach.

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 inclined to promote it. Although the limitations of this study (discussed in the next section) prevent it from offering definitive answers, it still provides some provocative initial answers to these important research and policy questions.

2. DATA

2.1 Sampling Procedure

In November 1998, a 16-page self-administered survey was distributed to a sample of employees of six California state agencies that have kept active telecommuting programs since the original pilot program in 1988 (JALA Assoc., 1990; Kitamura *et al*., 1990). 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 the importance of participation by non-telecommuters and former telecommuters as well as current telecommuters. Staff within each agency served as the contact point for broadcasting the recruitment e-mail, distributing the surveys and collecting them (respondents could also mail the survey directly back to the University of California at Davis; in any event individual respondents and responses were not identified to agency staff). In some cases, staff made a targeted effort to recruit known telecommuters. 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 4, we weight respondents to reflect the proportions of telecommuters and non-telecommuters in the population as a whole, defined as the non-agricultural workforce in the United States[1].

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 report should be viewed with some caution. It is unknown the extent to which such trends are genuine, or an artifact of the sampling bias. 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

[1] Nationwide figures are used to weight the sample because reliable data on number of telecommuters at the California state level are not available.

private sector employees, although no particular hypotheses with respect to the current study present themselves. With these caveats kept firmly in mind, however, careful evaluation of the results will be valuable.

Our database contains 218 cases for which commute person-miles traveled can be computed in least at one of the 41 quarters studied. It will be seen later that for commute PMT to be computed at a given quarter, information on telecommuting frequency and commute length at that quarter is necessary. Every case for which we do not have this information in a certain quarter is considered missing for that quarter. The sample includes 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.

2.2 Survey Design

The self-administered written survey contained two 10-year timelines, each divided into 3-month periods. On the first timeline, current and former regular[2] 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. 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).

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.

[2] Regular telecommuting was defined as "at least two days a month on average, for at least three consecutive months".

2.3 Data Cleaning

For the purpose of this study, an entirely new main data file was created, alongside a number of complementary smaller files. In all these files, data were structured in a time series fashion for each case. That is, 41 variables were created for every general variable of interest (e.g. commute distance), that documented the value of that general variable at each quarter, from the fourth quarter of 1988 through the fourth quarter of 1998. Since this study is directly concerned with the amount of commute travel done by telecommuters and non-telecommuters, cases whose commute PMT could not be computed at any given quarter were coded as missing in that quarter. Only a few cases on average were lost because of this reason, as can be inferred from Table 12 (in the last quarter, for example, 214 cases are available for analysis). The complementary files included four files that identify the telecommuting status of each respondent in each quarter, according to each of the four definitions of telecommuter we present in Section 3, and one file that documents, for each case, quarters when a commute change took place and corresponding impacts. Five different types of commute change events were defined: residence relocation, workplace relocation, residence and workplace relocations, commute mode change, and commute distance change (defined as a change in commute distance without a change in either residential or job location, presumably due to a route change, and found only twice in the sample).

A side benefit of this detailed data processing was the identification of a number of data entry errors dating back to when the original data file was created. These findings prompted us in turn to look for suspicious cases and double check them by inspection of the original surveys.

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 3.2). 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. Critical examination of each of these cases determined whether to consider them outliers or not. Note that this determination is 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.

2.4 Descriptive Statistics for Demographic Variables

In this subsection we present descriptive statistics for some key demographic variables. The statistics for each of these variables are presented for the entire sample, as well as for cases grouped according to three telecommuting status categories: employees who were telecommuting at the sampling quarter (current telecommuters), employees who were not telecommuting at the sampling quarter but did telecommute before (former telecommuters), and employees who never telecommuted (never-telecommuters).

Table 1 presents the gender distribution for the total sample and for the three subsamples defined above. While there are proportionally more males who have never telecommuted than in the two telecommuter groups, females represent a clear majority in every one of the three subsamples shown as well as in the sample in general. Chi-square tests indicate no statistically significant association between gender and telecommuting status.

Table 1. Gender Composition

	Total sample		Current telecommuters		Former telecommuters		Never-telecommuters	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
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	62	100	35	100	121	100

In Table 2 we present the descriptive statistics for the age variable. While the median is relatively homogeneous across the telecommuting status groups, the appropriate t-tests show that the mean age of former telecommuters is significantly higher (at the 0.021 level, two-tailed test) than the mean age of never-telecommuters. This may simply reflect that some current never-telecommuters will eventually (when they are older) telecommute and become former telecommuters.

Table 2. Age Statistics

	Total sample	Current telecommuters	Former telecommuters	Never-telecommuters
N	217	62	35	120
Mean	43.21	43.19	44.69	42.79
Median	44.00	44.0	44.00	43.50
Mode	44	47	39[a]	44
Std. Deviation	8.73	8.596	8.887	8.778
Minimum	21	21	29	22
Maximum	74	61	60	74

[a]: Multiple modes exist. The smallest value is shown.

In Table 3. we present the descriptive statistics for the number of household members. Interestingly, although never-telecommuters are younger on average than former telecommuters as noted above, the average household sizes of the two groups are about equal at nearly three people each. Current telecommuters have slightly smaller households (2.7 people on average), in what seems a contradiction of the stereotype that the presence of children serves as one motivation to telecommute. However, neither ANOVA nor chi-square tests (where households with five or more members were consolidated into a single category to improve small cell counts) show a significant difference between groups in household size mean or distribution.

Table 3. Household Size Statistics

	Total sample	Current telecommuters	Former telecommuters	Never-telecommuters
N	218	62	35	121
Mean	2.84	2.66	3.00	2.89
Median	3.00	2.00	3.00	3.00
Mode	2	2	3	2
Std. Deviation	1.355	1.305	1.085	1.448
Minimum	1	1	1	1
Maximum	9	6	5	9

Table 4 presents the distribution of educational backgrounds of the respondents. Virtually every person who decided to participate in the survey (97.3%) has at least some college education, and more than half (57.7%) have at least completed a college degree. At the same time, the proportion of people who have adopted telecommuting tends to increase for higher-education categories.

Table 4. Educational Background Distribution

	Total sample		Current telecommuters		Former telecommuters		Never-telecommuters	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
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	52	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	34	97.1	120	99.2

The income distribution, shown in Table 5, is more symmetric than the education distribution. The clearest feature of this distribution is that most (76.7%) of the respondents in the lower two income categories never telecommuted. This may be correlated with their younger age and lower education: a disproportionate number of the never-telecommuters may be earlier in their careers and/or in jobs that are not well suited for telecommuting.

Table 5. Annual Personal Income Category Distribution

	Total sample		Current Telecommuters		Former telecommuters		Never-telecommuters	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
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	62	100	35	100	121	100

A clear majority of our sample (84%) lives in single-family housing units, as evidenced by Table 6. Chi-square tests (collapsing categories as needed to improve cell counts) show no significant difference in the distribution of type of dwelling within each of the three categories shown in the last three columns of Table 6 (current telecommuters, former telecommuters, never-telecommuters). For example, there is no significant difference in the distribution of dwelling type between current telecommuters and non-current telecommuters. Neither did a chi-square test show evidence of difference in the distribution of dwelling types across the three categories individually.

Table 6. Housing Type Distribution

	Total sample		Current telecommuters		Former telecommuters		Never-telecommuters	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Single-family house	184	84.4	54	87.1	28	80.0	102	84.3
Condo	12	5.5	6	9.7	1	2.9	5	4.1
Apartment	15	6.9	2	3.2	3	8.6	10	8.3
Duplex	5	2.3	-	-	2	5.7	3	2.5
Other	2	.9	-	-	1	2.9	1	.8
Total	218	100	62	100	35	100	121	100

Table 7 shows the distribution of types of residential areas for the total sample as well as for the groups of current telecommuters, former telecommuters, and never-telecommuters. A chi-square test (collapsing the cells corresponding to small city, town or village, and countryside) showed no significant difference in the distribution of residential area types across the three subsegments. Of the 18 individuals living in the countryside, nine are current telecommuters and one is a former telecommuter. In fact, the nine current telecommuters living in the countryside constitute 14.5% of all the current telecommuters (whereas only 8.3% of the sample as a whole lives in the countryside). This distribution may suggest an association between the decision to telecommute and commute distance and/or lifestyle preferences related to non-urbanized areas.

Table 7. Distribution of Types of Residential Areas

	Total sample		Current telecommuters		Former telecommuters		Never-telecommuters	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Large city	91	41.7	21	33.9	15	42.9	55	45.5
Suburb 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	120	99.2

2.5 Telecommuting Engagement

Table 8 presents a quarter-by-quarter tabulation of the number of telecommuters and their average telecommuting frequency, expressed in two different units: times per month and times per week. The respondents reported their telecommuting frequency for a given quarter in either of these units; we convert from one unit to another using the factor of 4.33 weeks/month. The analysis of the data in Table 8 is presented in Section 4.2 (see Figure 3 and accompanying discussion).

Table 8. Telecommuting Engagement and Mean Frequency at Each Quarter

Quarter	Number of telecommuters	Mean telecommuting frequency [times/month]	Mean telecommuting frequency [times/week]
4/1988	5	11.6910	2.700
1/1989	9	10.0850	2.329
2/1989	9	10.0850	2.329
3/1989	12	11.1721	2.580
4/1989	13	10.9788	2.536
1/1990	16	10.2734	2.373
2/1990	14	8.6482	1.997
3/1990	16	9.1909	2.123
4/1990	17	8.6503	1.998
1/1991	16	8.6497	1.998
2/1991	15	8.4937	1.962
3/1991	16	8.5041	1.964
4/1991	17	7.5581	1.746

Quarter	Number of telecommuters	Mean telecommuting frequency [times/month]	Mean telecommuting frequency [times/week]
1/1992	20	6.4164	1.482
2/1992	22	7.2108	1.665
3/1992	22	7.1616	1.654
4/1992	19	7.5604	1.746
1/1993	22	7.4076	1.711
2/1993	23	7.2303	1.670
3/1993	26	7.3602	1.700
4/1993	26	7.3634	1.701
1/1994	31	7.3577	1.699
2/1994	31	7.5941	1.754
3/1994	33	7.9338	1.832
4/1994	36	8.0569	1.861
1/1995	45	6.7791	1.566
2/1995	48	7.5281	1.739
3/1995	47	6.9850	1.613
4/1995	48	7.0702	1.633
1/1996	46	6.6969	1.547
2/1996	47	6.5160	1.505
3/1996	49	6.7805	1.566
4/1996	48	7.0916	1.638
1/1997	58	6.8408	1.580
2/1997	58	6.9037	1.594
3/1997	60	6.9137	1.597
4/1997	59	6.9730	1.610
1/1998	63	6.8964	1.593
2/1998	67	6.8489	1.582
3/1998	65	6.5254	1.507
4/1998	62	6.7310	1.555

The time structure of our data allows us to explore several facets of the dynamics of telecommuting adoption. Table 9 presents a quarter-by-quarter tabulation of the number of new (first-time) telecommuters, the number of individuals that telecommute for the last time (within the study period), the number of lapsing[3] telecommuters, and the total number of telecommuters in that quarter. Our data confirm the observations of previous studies that multiple telecommuting episodes are a common occurrence (Varma *et al*., 1998). This conclusion may be inferred from Table 8 by noticing that the number of lapsing telecommuters usually exceeds the number of last-time telecommuters in a given quarter.

[3] We define a lapsing telecommuter in a certain quarter to be a person who is not telecommuting in that quarter, but who telecommutes in the preceding quarter and at least one succeeding quarter within the study period. For the last quarter of data collection, it is unknown whether a telecommuter will quit, lapse, or continue indefinitely; all are simply considered "current telecommuters" for that quarter.

Table 9. Debuting Telecommuters, Telecommuting Quitters, Lapsing Telecommuters

Quarter	Number of first-time telecommuters	Number of last-time telecommuters	Number of lapsing telecommuters	Number of current telecommuters
4/1988	5	0	0	5
1/1989	4	0	0	9
2/1989	0	0	0	9
3/1989	3	0	0	12
4/1989	1	0	0	13
1/1990	4	2	1	16
2/1990	0	0	0	14
3/1990	2	0	0	16
4/1990	1	0	0	17
1/1991	1	0	2	16
2/1991	0	0	1	15
3/1991	1	0	0	16
4/1991	1	0	1	17
1/1992	6	0	3	20
2/1992	0	0	0	22
3/1992	1	0	1	22
4/1992	0	1	4	19
1/1993	2	0	2	22
2/1993	1	0	0	23
3/1993	4	0	2	26
4/1993	0	0	2	26
1/1994	5	0	2	31
2/1994	2	0	2	31
3/1994	3	0	2	33
4/1994	2	2	1	36
1/1995	7	0	0	45
2/1995	3	1	1	48
3/1995	2	0	4	47
4/1995	3	2	4	48
1/1996	4	3	5	46
2/1996	1	1	2	47
3/1996	2	2	1	49
4/1996	2	2	2	48
1/1997	7	0	0	58
2/1997	2	2	2	58
3/1997	3	3	2	60
4/1997	1	1	1	59
1/1998	4	3*	2	63
2/1998	4	5	2	67
3/1998	2	5	1	65
4/1998	1	-	-	62

* Due to a coding error discovered very late in the project, one of these three people was misclassified, since telecommuting information for the final three quarters was missing in the database. This person actually continued telecommuting through the end of the study period and hence should be classified as a current telecommuter. For the remainder of this report, the final three quarters of information for this case are treated as missing. The database has been corrected for future analyses.

Table 9 shows the distribution of telecommuting debuts to be somewhat more concentrated toward the later years, closer to the time of data collection. On average, about 1.6 times as many (12.0) telecommuters started per year in the last five years as in the first 20 quarters (7.4 per year). To some extent this is to be expected, since the adoption of telecommuting has increased over time in the workforce at large. This greater adoption rate is disproportionate in our sample, however, as indicated by the generally decreasing weights required to make sample telecommuters reflect the proportions of the workforce as a whole (see Table 12 of Section 3.5). Thus, the disproportionately heavy rate of later entry into telecommuting is probably a consequence of the retrospective nature of these data. There is a clear pattern of more starts in the first quarter of many years. This may be because the post-holiday New Year season is a time of new starts of many kinds.

Similarly, the distribution of quitting telecommuters is also more concentrated toward the end, with nearly half of the "quits" (16 of 34) occurring in the 1.25 years prior to the last quarter of data collection. Even more than the distribution of starts, however, the classification of a telecommuter as quitting or only lapsed is very much an artifact of the data collection cutoff point. If that cutoff were extended later in time, some of those seen as quitters here would have started telecommuting again and should more properly have been classified as lapsed. In survival theory terminology, every observation in the sample is censored since its telecommuting status could change at a later point in time, in either direction. This obviously differs from the classical medical applications of survival theory (and in fact makes it impossible to apply that technique to modeling *total* telecommuting duration, although perhaps it could apply to modeling the duration of the first telecommuting episode, or all individual episodes as opposed to total duration), since in medicine, once a patient dies her status is not subject to later change. To study patterns of duration of individual telecommuting episodes, one needs to account for censored observations at the last quarter, since for cases that are still telecommuting then we do not observe the actual duration. Similarly, for the analysis of duration of intervals between telecommuting episodes, or of time before adoption of telecommuting, the censoring would apply to those cases who are not telecommuting in the last quarter. Given the sampling procedure used, more than half of the telecommuting individuals in our sample would be censored at the last quarter, as the concentration of telecommuters increases toward the final quarters (the maximum of 67 being obtained at the second quarter before the last).

2.6 One-Way Commute Length and Time

In Section 4 we will analyze commute distance traveled by telecommuting status. Here, we include the descriptive statistics corresponding to the basic commute variables, one-way distance and time, for the entire sample combined (see Table 10 and Figure 1).

Table 10. Descriptive Statistics for One-Way Commute Length and Time at Each Quarter

Quarter	Commute length (miles)			Commute time (minutes)			Mean speed (miles per hour)
	N	Mean	Std. Deviation	N	Mean	Std. Deviation	
4/1988	200	13.587	12.601	199	26.636	18.357	30.607
1/1989	199	13.762	12.598	198	26.919	18.466	30.674
2/1989	198	13.702	12.540	199	26.784	18.470	30.694
3/1989	199	14.689	19.685	200	27.682	23.692	31.837
4/1989	200	14.916	19.662	200	27.998	23.575	31.965
1/1990	200	14.260	12.965	201	27.149	18.132	31.514
2/1990	201	14.863	13.044	202	28.215	18.105	31.606
3/1990	202	16.172	16.094	201	29.072	18.875	33.376
4/1990	201	16.115	14.716	200	29.305	18.997	32.994
1/1991	200	16.453	14.646	203	29.623	18.740	33.325
2/1991	203	16.128	14.016	203	29.515	18.805	32.786
3/1991	203	15.734	13.475	203	29.012	18.304	32.540
4/1991	203	15.804	13.409	204	29.321	18.662	32.340
1/1992	204	15.864	13.501	206	29.541	18.843	32.221
2/1992	206	16.112	13.730	206	29.655	18.809	32.598
3/1992	206	16.112	13.366	207	29.843	19.041	32.394
4/1992	207	16.590	13.945	207	30.688	19.990	32.437
1/1993	207	17.173	14.916	208	31.329	20.819	32.888
2/1993	208	17.440	14.906	209	31.502	20.697	33.217
3/1993	209	17.560	14.634	209	31.660	20.237	33.278
4/1993	209	17.158	13.902	209	31.072	19.485	33.132
1/1994	209	17.111	14.579	211	30.550	19.173	33.606
2/1994	211	17.519	14.461	211	31.185	19.215	33.706
3/1994	211	17.598	14.528	208	31.351	19.320	33.680
4/1994	208	17.827	14.510	208	32.048	19.696	33.376
1/1995	208	17.862	14.104	209	31.943	18.530	33.550
2/1995	209	17.897	14.108	211	32.052	18.706	33.502
3/1995	211	18.354	14.325	210	32.395	18.244	33.993
4/1995	210	18.313	14.416	212	32.288	18.090	34.030
1/1996	212	18.653	14.683	211	32.699	18.104	34.226
2/1996	211	18.332	14.387	212	32.226	18.096	34.132
3/1996	213	18.647	15.048	212	32.123	18.468	34.829
4/1996	213	18.558	15.008	212	32.113	18.492	34.673
1/1997	213	18.411	15.040	212	31.851	18.556	34.682
2/1997	213	18.642	15.363	213	32.545	19.115	34.369
3/1997	214	18.522	15.234	214	32.738	19.756	33.946

Quarter	Commute length (miles)			Commute time (minutes)			Mean speed (miles per hour)
	N	Mean	Std. Deviation	N	Mean	Std. Deviation	
4/1997	215	18.358	15.331	214	32.355	19.716	34.044
1/1998	215	18.317	15.430	213	32.596	20.520	33.717
2/1998	215	18.233	15.492	213	32.289	20.165	33.880
3/1998	215	18.271	15.615	212	32.476	20.550	33.756
4/1998	214	18.404	15.651	212	32.689	20.514	33.781

The one-way commute length shows an increasing trend over the ten-year period, an unsurprising result in view of the many sources reporting the same, including the Nationwide Personal Travel Survey (NPTS). In our sample, initial (1988) mean commute lengths of 13.6 miles increase to 18-19 miles, and remain there for the last 3.5 years of the study period. There is a similar increase in commute time, seemingly in disagreement with studies reporting that while commute distances increase, commute times remain rather stable in major metropolitan areas (Gordon *et al.*, 1991; Levinson and Kumar, 1994). In our sample, the mean commute time increases from 26.6 to 32.7 minutes. The average commute length and time for our sample are larger than for the U.S. as a whole. The NPTS reports nationwide average commute trip lengths of 10.65 and 11.63 miles for the years 1990 and 1995 respectively. For the same years, the reported average commute travel times were 19.60 and 20.65 minutes respectively. For reference, the 2000 Census revealed a mean travel time to work of 25.4 minutes for Sacramento County. 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. However, we will see in Section 4 that telecommuters' commute lengths are greater than those of non-telecommuters, and the fact that telecommuters are overrepresented in our sample also accounts in part for the longer-than-average commutes seen here.

Despite the lengthening commute distances and times, commute speeds actually increase over the study period, indicating that the increases in travel times are proportionately less than those for distances. This may seem to be at odds with studies indicating worsening congestion in most metropolitan areas over time, while agreeing with other studies that found increasing commute speeds (Gordon *et al.*, 1991; Levinson and Kumar, 1994). Aggregate or system-level indicators of congestion can mask substantial counteracting adjustments at the disaggregate level that result in higher commute speeds for individuals, such as relocations away from congested areas, shifts from transit to auto, and changes in departure time. Thus, it is quite possible for aggregate measures of congestion in a region to worsen over time (reflecting increases in population and employment as well as per capita vehicle miles traveled), even while individuals on average improve their situations (Salomon and Mokhtarian, 1997). One might argue that an increase in commute time is not an improvement, but if that time is passed at higher speeds (suggesting less stress due to congestion), the individual might consider it to be one. These trends are portrayed in Figure 1. Linear regressions of both commute time and distance on calendar time yield statistically significant coefficients ($p = 0.000$), while a logarithmic fit of the evolution of average speed gives an R^2 of 0.813.

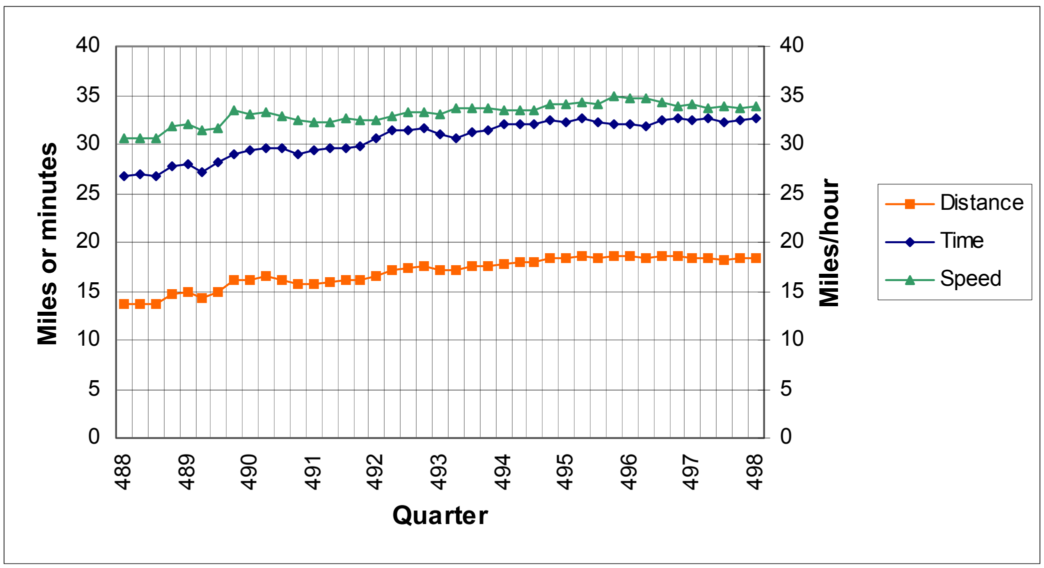

Figure 1. Trends in One-Way Commute Length, Commute Time, and Average Commute Speed

3. METHODOLOGY

3.1 Introduction

While the benefits (and potential costs) of telecommuting are not all (directly) related to transportation, in this study we are focusing on the perspective of transport policy. Within this context, our primary interest is in the joint impact of residential/job location and telecommuting on distance traveled. While there is quite likely a *behavioral* causal link in the opposite direction (long distances traveled may motivate relocations and/or telecommuting), our analysis here is of the purely *algebraic* causal relationship that distance per commute (a function of residential and job location) times frequency of commuting (a function of telecommuting) equals total commute distance traveled. Two operationalizations of distance traveled that are of central importance to evaluating the impacts of telecommuting on the efficiency of the transportation system and air quality are person-miles traveled (PMT) and vehicle-miles traveled (VMT).

One important objective of telecommuting as a transportation demand management strategy is to reduce overall VMT, thereby reducing peak-period congestion, mobile source emissions, and ideally also fuel consumption. However, the impacts of telecommuting on PMT are also of interest. Previous studies suggest that the adoption of telecommuting seems more appealing to people with longer commutes. Conversely, it has been hypothesized that the access to telecommuting options may induce people to move farther from the workplace (e.g. Lund and Mokhtarian, 1994). Either way, it is plausible that the decisions to telecommute, and to do it with a certain frequency, are regulated by the desire of people to keep their commute PMT at acceptable levels.

While our data contain some information on travel behavior for purposes other than going to work, it is only for this category that we have measures quantified in miles for the entire ten-year period of study. Thus, our analysis concentrates on calculating person and vehicle commute miles traveled at each quarter, and comparing those measures between telecommuters and non-telecommuters. To do this, however, requires some simplifying assumptions which we now describe.

3.2 Calculation of Commute PMT

The (two-way) commute person-miles traveled (PMT) by person *i* in quarter *q* is estimated as

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

where *D* is the reported commute distance, *wd* is the number of working days that apply to California state employees in that quarter, and *tcf* is the telecommuting frequency in that quarter. 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, or commute on the weekends as well as during the week. 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. Nevertheless, our simple formula is a reasonable best guess for commute PMT, and its uniform application across the sample should offer a fairly accurate estimate of changes over time and differences across subgroups. On a quarter-by-quarter basis, cases whose PMT lay beyond three standard deviations from the mean, and were isolated from the rest, were considered outliers and excluded from this portion of the analysis.

To obtain the mean daily commute PMT for person *i* in quarter *q*, we divide the last expression by the number of working days in the respective quarter:

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

This measure is in some ways a more illustrative estimate of the amount of commute travel since it avoids the spurious impact of the variation in the number of working days present in the quarterly PMT estimate.

3.3 Calculation of Commute VMT

While our PMT calculation provides the best indicator of total commute distance traveled by our respondents, it has been argued elsewhere (Mokhtarian, 1991; Koenig *et al*., 1996) that in terms of evaluating the impacts of telecommuting on congestion and air quality, it is distance traveled in the drive alone mode that is the most important indicator. Increases or decreases in commute distance traveled by walking or biking have no impact on congestion and air quality in and of themselves. Similarly, at least at the margin, an additional passenger more or less on a transit vehicle or in a carpool will have no impact. Thus, it is also important to analyze commute distance traveled in a personal vehicle, specifically in drive alone mode.

For the 10-year timeline on which respondents indicated job and residential relocations, they were asked to write in the commute distances, times, and primary means of transportation (i.e. "the means of transportation you most often used") for the commute after each relocation. The respondents were cautioned that "If you used a car, don't just say 'car' but specify whether it was 'drive alone' or 'carpool'", and those specific cases were used in the example provided. Nevertheless, a number of respondents indicated "car" as their commute mode[4]. Further, a number of respondents reported using more than one mode for a given commute, without specifying the number of miles allocated to each mode. A combined mode may also indicate different modes chosen on different days.

The commute modes/mode combinations reported by the respondents were sorted into 33 categories. Table 11 shows the frequencies for each mode combination in the fourth quarter of 1988 and in the fourth quarter of 1998, and confirms the expectation that modes involving a personal vehicle would dominate.

[4] While the "car" category is somewhat ambiguous in that it can be interpreted either as "driving alone" or "carpooling" or both, we believe that in most cases the respondents reporting "car" as their commute mode meant "drive alone". However, the data do not provide the means to discern whether this is indeed the case.

Table 11. Commute Mode Frequencies in the Fourth Quarters of 1988 and 1998

Code	Mode Combination	Frequency in 4/1988	Percent	Frequency in 4/1998	Percent
0	Car	25	11.5	19	8.7
1	Drive alone	107	49.1	123	56.4
2	Carpool	26	11.9	23	10.6
3	Vanpool	4	1.8	4	1.8
4	Light rail	2	.9	3	1.4
5	Bus	4	1.8	8	3.7
6	Walk	5	2.3	4	1.8
7	Bike	7	3.2	3	1.4
8	BART	1	.5	-	-
9	Train	1	.5	-	-
10	Transit	2	.9	-	-
11	Drive alone, carpool	5	2.3	8	3.7
12	Drive alone, light rail	1	.5	-	-
13	Drive alone, bus	-	-	1	.5
14	Drive alone, BART	-	-	1	.5
15	Car, light rail	1	.5	2	.9
16	Car, bus	2	.9	-	-
17	Car, bike	-	-	-	-
18	Car, train	1	0.5	3	1.4
19	Car, transit	-	-	-	-
20	Carpool, light rail	-	-	-	-
21	Carpool, bus	2	0.9	4	1.8
22	Carpool, bike	-	-	1	.5
23	Carpool, train	-	-	-	-
24	Bus, light rail	-	-	1	.5
25	Light rail, bike	-	-	1	.5
26	Bus, walk	-	-	-	-
27	Bus, bike	-	-	1	.5
28	Bus, train	-	-	-	-
29	Bus, ferry	-	-	-	-
30	BART, walk	-	-	-	-
31	Bike, walk	1	0.5	2	.9
32	Walk, train	-	-	-	-
33	Drive alone, walk	-	-	-	-
Total		197	90.4	212	97.2
Missing		21	9.6	6	2.8

In view of both the failure of some respondents to specify whether their car commute was driving alone or carpooling, and the presence of multiple modes in unknown proportions, it was not possible to calculate drive alone VMT unequivocally. Instead, we created two definitions of commute VMT. One, VMT_L, comprises the miles traveled to/from work by those respondents who indicated "drive alone" as their only commute mode. The aggregation of this measure across the sample represents a lower bound on the commute-related drive-alone VMT. The second, VMT_U, comprises the miles traveled by respondents whose reported commute mode is "drive alone", "car", or any multimodal combination that includes either of these. Since we have no way to discern which portion of a multimodal commute corresponds to any particular mode, VMT_U makes the worst-case assumption that the entire distance may have been driven alone. Consequently, the sample-wide aggregation of this measure represents an upper bound on the commute-related drive-alone VMT.

3.4 Alternative Definitions of a Telecommuter

As mentioned in Section 3.1, a natural goal of this study is to compare VMT and PMT for telecommuters and non-telecommuters. The structure of our data allows us to perform this comparison for a sequence of 41 quarters, and to observe the resulting patterns of evolution along this 10-year study period. In order to carry this out we need to decide on appropriate operationalizations for the relevant variables. We have described above the way commute PMT and VMT in a given quarter were operationalized. There we saw that the individual PMT (and hence VMT) depends on the telecommuting status of the person in that quarter. Further, the definition of the telecommuting status for each individual in each quarter is necessary to perform comparisons between groups. In this context the question arises: how to classify an employee as telecommuter or non-telecommuter? A number of classification approaches have merit; we suggest four possibilities.

1. The most straightforward operationalization of telecommuting status is to consider a person to be a telecommuter in the quarters when she is telecommuting. This definition suggests the identification of telecommuters at quarter *q* by means of a dummy variable such that $\text{TCer}_{1iq} = 1$ if person *i* telecommutes in quarter *q*, and $\text{TCer}_{1iq} = 0$ otherwise.
2. Empirical work (e.g. Varma *et al*., 1998) has found that repeated telecommuting episodes are common, suggesting that there is a proclivity for former telecommuters to telecommute again in the future. In view of this, it may be relevant to identify employees as telecommuters once they have telecommuted for the first time. This would lead to a definition of telecommuter by using a dummy variable such that $\text{TCer}_{2iq} = 1$ if person *i* has telecommuted in any quarter preceding or including quarter *q*, and $\text{TCer}_{2iq} = 0$ otherwise.

3. It can also be argued that the circumstances relating to the adoption of telecommuting probably arise some time before the adoption, and/or remain some time after quitting telecommuting. In that case, the characteristics of a telecommuter, and/or causes and effects of telecommuting, may be better captured by studying that person some time before and some time after he telecommutes. This suggests operationalizing the concept of telecommuter by a dummy variable such that $TCer_{3iq} = 1$ if person *i* telecommutes during quarters *q*-1, *q*, or *q*+1, and $TCer_{3iq} = 0$ otherwise.
4. Finally, one might hypothesize that the kinds of people who *ever* telecommute are inherently different from those who *never* do it, even when they do not happen to be telecommuting at the moment. This suggests defining a dummy variable such that $TCer_{4iq} = 1$ if person *i* telecommutes in any quarter, and $TCer_{4iq} = 0$ otherwise. Of course, this definition will unavoidably misclassify as never-telecommuters those who start telecommuting sometime in the future.

In this study we use primarily the first definition of a telecommuter, but it would be of interest to explore the other definitions in future research using these data.

3.5 Weighting the Sample

It was discussed in Section 2.1 that the sampling scheme (by design) resulted in telecommuters being overrepresented in the study sample, particularly (more through a likely self-selection bias than by design) in the later quarters. In the study of commute-related person-miles traveled, we need to exercise caution in giving observations for telecommuters and non-telecommuters their correct weight. For some analyses, such as comparing the per-capita PMT of telecommuters in our sample to that of non-telecommuters, no weighting is necessary, as we deal with mean values of person-miles traveled separately for those in each category. However, there are additional questions of interest with regard to PMT patterns. For example, how does the proportion of total commute PMT for which telecommuters are responsible compare to their proportion in the workforce? To answer questions like this, weighting the numbers of telecommuters and non-telecommuters becomes necessary, so that their respective proportions reflect those for the actual working population.

To calculate the weights for the denominator, 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 weighting proceeded in the following way. 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. Analogous conditions would need to be met for non-telecommuters. This implies the following equations:

$$\frac{PopTC}{PopTC + PopNTC} = w_T \frac{TC}{TC + NTC}$$

$$\frac{PopNTC}{PopTC + PopNTC} = w_{NT} \frac{NTC}{TC + NTC}$$

$$= 1 - w_T \frac{TC}{TC + NTC}$$

where $PopTC$ = number of telecommuters in the working population,

$PopNTC$ = number of non-telecommuters in the working population,
TC = number of telecommuters in the sample,
NTC = number of non-telecommuters in the sample,
w_T = weight applied to sample telecommuters,
w_{NT} = weight applied to sample non-telecommuters.

The ratios on the left-hand side of the equations above take on the observed and interpolated values. The weights applied to each telecommuter in each quarter are then clearly the ratio of the population proportion of telecommuters to their sample proportion, and similarly for non-telecommuters.

$$w_T = \frac{PopTC}{PopTC + PopNTC} \bigg/ \frac{TC}{TC + NTC}$$
$$w_{NT} = \frac{PopNTC}{PopTC + PopNTC} \bigg/ \frac{NTC}{TC + NTC}$$

The weighted numbers of telecommuters and of non-telecommuters in the sample, *WTC* and *WNTC* respectively, follow directly:

$$WTC = w_T TC = \frac{PopTC}{PopTC + PopNTC}(TC + NTC)$$
$$WNTC = w_{NT} NTC = \left(1 - \frac{PopTC}{PopTC + PopNTC}\right)(TC + NTC)$$

In our sample w_T is less than one for every quarter, while w_{NT} is greater than one. Thus, the contribution of the oversampled telecommuters is dampened and that of the undersampled non-telecommuters is inflated by application of the respective weights.

The weights obtained as described 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 2.1. 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 12 presents the values of the variables involved at each quarter. It should be reiterated that 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 19 cases whose missing data preclude the calculation of their PMT.

Table 12. Distribution of Telecommuters and Non-Telecommuters 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

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
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

4. RESULTS

In this section we present the key results of the study. We begin by analyzing one-way commute length (Section 4.1) and telecommuting frequency (Section 4.2), which are the main determinants of commute PMT and VMT (Section 4.3). We conclude with a descriptive analysis of residential location changes (Section 4.4).

4.1 One-Way Commute Length

In Section 2.6 we described the trends in average one-way commute length for the entire sample. Here we present the evolution of the same variable distinguished by telecommuting status at each quarter.

We find that telecommuters have higher mean commute lengths across the board (see Figure 2). Table 13 shows the means and standard deviations of the one-way commute lengths of each group (telecommuters and non-telecommuters in a given quarter) on a quarter-by-quarter basis, indicating also the difference in means between telecommuters and non-telecommuters, in quarters where that difference is statistically significant at least at the 0.05 level. Figure 2 also indicates these quarters by enlarged markers. Although commute times are not further analyzed in this report, it is interesting to note that average commute times are significantly different in only six quarters (compared to 18 for distance), including two for which distance was not significantly different. One might have expected commute time to have been more strongly associated with telecommuting than commute distance, but that does not appear to be the case here.

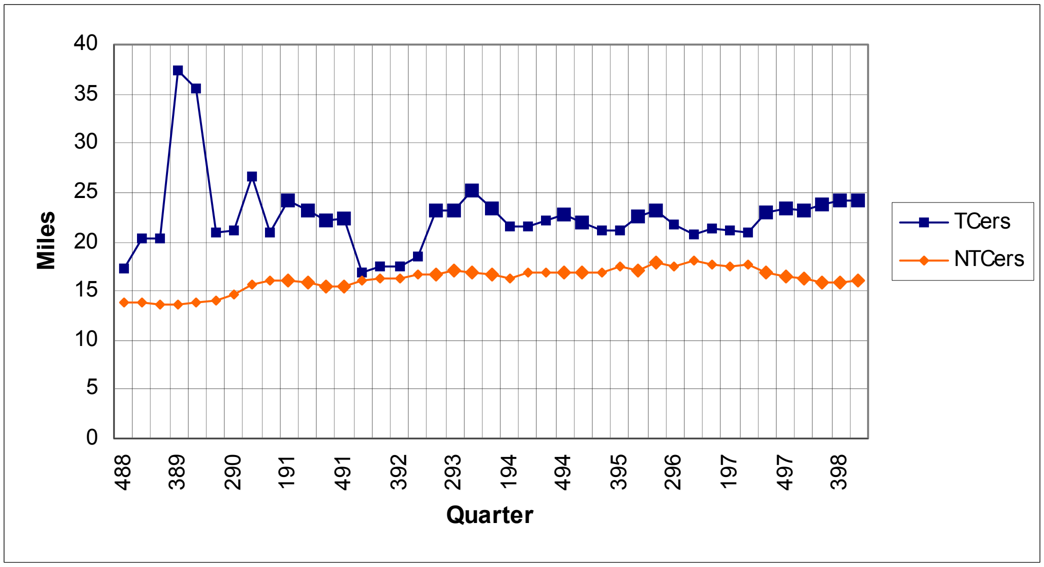

Figure 2. Evolution of Mean One-Way Commute Lengths of Telecommuters and Non-Telecommuters

Table 13. Commute Length for Telecommuters and Non-Telecommuters

Quarter	Non-telecommuters			Telecommuters			Statistically significant difference (miles)
	N	Mean commute length (miles)	Standard deviation	N	Mean commute length (miles)	Standard deviation	
488	194	13.494	12.623	5	17.200	12.458	
189	189	13.449	12.386	9	20.333	15.890	
289	190	13.388	12.323	9	20.333	15.890	
389	188	13.243	12.293	12	37.333	62.015	
489	187	13.477	12.315	13	35.615	59.697	
190	185	13.682	12.394	16	20.938	17.472	
290	188	14.400	12.489	14	21.071	18.499	
390	185	15.273	13.998	16	26.563	30.415	
490	183	15.672	14.453	17	20.882	17.051	
191	187	15.797	14.146	16	24.125	18.413	8.328
291	188	15.574	13.501	15	23.067	18.549	7.492
391	187	15.193	12.911	16	22.063	18.219	6.870
491	187	15.203	12.843	17	22.412	17.699	7.209
192	186	15.762	13.710	20	16.813	11.641	
292	184	15.939	13.967	22	17.557	11.745	
392	185	15.956	13.497	22	17.420	12.430	
492	188	16.399	14.076	19	18.487	12.766	
193	186	16.462	14.305	22	23.182	18.659	6.720
293	186	16.726	14.339	23	23.217	18.231	6.492
393	183	16.475	13.814	26	25.192	17.978	8.717
493	183	16.267	13.310	26	23.423	16.478	7.156
194	180	16.341	14.290	31	21.581	15.656	
294	180	16.814	14.183	31	21.613	15.594	
394	175	16.757	14.373	33	22.061	14.750	
494	172	16.779	13.851	36	22.833	16.636	6.054
195	164	16.763	13.582	45	21.867	15.366	5.104
295	163	16.922	13.643	48	21.208	15.275	
395	163	17.523	13.890	47	21.234	15.557	
495	164	17.050	13.445	48	22.625	16.776	5.575
196	165	17.402	13.399	46	23.141	18.040	5.739
296	166	17.363	13.591	47	21.755	16.615	
396	164	18.008	14.741	49	20.786	16.006	
496	165	17.735	13.768	48	21.385	18.548	
197	155	17.420	13.488	58	21.060	18.440	
297	156	17.743	14.024	58	21.060	18.411	
397	155	16.792	13.051	60	22.992	19.208	6.200
497	156	16.439	13.066	59	23.432	19.361	6.993
198	152	16.340	12.747	63	23.087	19.833	6.747
298	148	15.760	12.490	67	23.694	19.666	7.934
398	149	15.822	12.621	65	23.885	19.930	8.063
498	152	16.118	12.757	62	24.008	20.188	7.890

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 2.3, they were retained for this analysis.

It is interesting to note how the difference in mean distance becomes more systematically significant toward the final quarters. In fact, although for most of the study period the non-telecommuters' commute lengths display the same increasing trend as for the whole sample shown in Figure 1 — not surprising since non-telecommuters dominate the sample — in the last six quarters the non-telecommuters' mean commute lengths actually decline while the telecommuters' rise, resulting in the flat trend shown in Figure 1 for that period. Since the final six observations for the telecommuters lie well within the range of fluctuation across the entire study period, it seems unlikely (although possible) that those figures are an artifact of the self-selection bias discussed in Section 2.1. This trend may be associated with the diffusion of telecommuting in time within the sample. It may also be related to the hypothesized association between telecommuting adoption and residence relocation farther from the workplace, an undesirable possible side effect of telecommuting.

To elaborate on these two possible explanations, let us first assume that people in the sample maintained the same commute distances throughout the study period. Under this scenario, at the early stages of the telecommuting program, when only a small number of employees adopted the new working arrangement, longer commute distances were more evenly distributed between telecommuters and non-telecommuters. As telecommuting diffused (it became available as an alternative, or employees started considering the alternative), it was found more appealing to workers with longer commutes, resulting in a net flux of long-distance commuters from the non-telecommuting to the telecommuting group. This process would eventually result in more significant differences in mean commute distances between the two groups, as shown in Table 13.

Now let us release the assumption that people in the sample kept their commute distances constant. It is possible to envision telecommuting becoming more appealing to people who relocated their residences farther from their workplaces (or vice versa), for other reasons. This is really just a further manifestation of the first explanation: people with longer commute distances are more motivated to consider telecommuting (a hypothesis which has been previously corroborated empirically for commute time by Mokhtarian and Salomon, 1997, and Sullivan *et al*., 1993). One may further hypothesize that the ability to telecommute may act as a facilitator of such relocations, i.e. be a substantial motivation for making the move in the first place. In that case, telecommuting becomes not just an effect but a cause of the relocation.

Thus, two processes were probably occurring simultaneously in the sample: (a) as people moved farther from work for conventional reasons, they became more inclined to adopt telecommuting, in which case telecommuting could be viewed as a purely beneficial strategy to reduce commute-related VMT; and (b) as telecommuting became available to them, relocating farther from work became more attractive (or less costly), in which case telecommuting could be viewed as a malignant incentive for increased decentralization of residences. According with the view that jobs follow workers to suburban areas, this decentralization of residences could in turn promote further decentralization of jobs over time. The combination of these two processes helps explain the rise in statistically significant differences in mean commute lengths observed in Table 13.

There is another caveat regarding the interpretation of the comparative results presented herein. A comprehensive analysis of the association between telecommuting status and the patterns shown should ascertain the extent to which telecommuting was an option for non-telecommuters. However, we are able to assess this condition only at the time the data were collected. This issue is more extensively discussed in Mokhtarian and Salomon (1996). Suffice it to say here that whenever we compare the time distribution of characteristics of telecommuters and non-telecommuters, we need to remember that the alternative of telecommuting might not be contained in the choice set of some non-telecommuters.

Since an individual's one-way commute length changes across time with residential and job relocations, it is useful to get a sense for the number and nature of such relocations in the sample. Table 14 presents several indicators of residential and job mobility for telecommuters and non-telecommuters as identified by each of the four definitions suggested in Section 3.4. The first two columns show the number of residential and job relocations for each of the segments. The next two columns show the average changes in one-way commute length after residential or job relocations done while being a telecommuter versus those made while not a telecommuter, according to each of the four definitions of telecommuter. For example, we see that the average change in commute length after residential relocations done in a telecommuting quarter is -0.39 miles — that is, a reduction in net commute distance. The last column shows the averages of the changes in commute length after any type of relocation: residential or job.

Table 14. Average Variation in One-way Commute Length After All Residential and Job Relocations

Telecommuter definition	Telecommuting status (person-quarters)	Number of residential relocations (movers)	Number of job relocations (movers)	Average change in commute miles after residential relocations	Average change in commute miles after job relocations	Average change in commute miles after any relocation
1. Telecommuter	TC (1356)	21 (14)	20 (12)	-0.39	5.21	4.30
	NTC (7163)	235 (115)	208 (106)	2.57	1.17	1.93
2. After Telecommuter	TC (1885)	37 (25)	30 (18)	-0.73	0.72	0.63
	NTC (6634)	227 (106)	209 (100)	2.88	1.79	2.63
3. Before-After Telecommuter	TC (1576)	33 (25)	27 (19)	4.66	4.18	4.30
	NTC (6943)	235 (110)	212 (102)	1.74	1.34	1.68
4. Ever Telecommuter	TC (3799)	105 (53)	103 (46)	4.65	3.42	3.73
	NTC (4961)	164 (70)	139 (64)	0.89	1.73	1.01

Thus we see, for example, that residential relocations made during a telecommuting quarter (definition 1) are actually *closer* to work on average (by 0.39 miles), while residential relocations made in non-telecommuting quarters (whether by never-telecommuters or stopped or lapsed telecommuters) average 2.6 miles *farther* from work.

A similar result appears in comparing residential moves of "after telecommuters" (current and former telecommuters) to those who never telecommuted or hadn't yet started at the time of the move (definition 2). These findings obviously do not support the hypothesis that telecommuting will stimulate moves farther from work. On the other hand, the picture changes dramatically when the telecommuting definition is taken to include the quarter before and quarter after an actual telecommute episode (definition 3). Residential moves in those telecommuting or telecommuting-adjacent quarters are substantially farther from work on average than those of non-telecommuters' moves (4.7 miles versus 1.7 miles). Comparing this to the result for definition 2 (which counts quarters after telecommuting as "telecommuter") suggests that it tends to be moves *before telecommuting begins* that are the longer-distance ones. This in turn suggests (but does not prove) that the decision to telecommute tends to be a consequence rather than a cause of the move. Results for job moves and all moves combined under definitions 1, 3, and 4, are similar to this.

The respondents were asked how important a factor the ability to telework was in the decision to relocate their residence, for the three last residential moves. The rows in Table 15 present the five options that respondents were given to answer this question, and the columns show some descriptive statistics of the change in one-way commute length that resulted from the last residential relocation. The mean of this change increases markedly as the household gives more importance to the ability to telework in its decision to move, which supports the idea that the ability to telework *does* prompt longer-distance moves. However, teleworking was accorded any importance at all for only 12 of the 97 most recent moves in the sample, indicating that this effect is at work in only a minority of cases.

Table 15. Mean Commute Length Change After Last Residential Relocation vs. Importance of Ability to Telework as a Factor to Relocate

	N	Change in Commute Length After Relocation			
		Mean	Std. Deviation	Minimum	Maximum
Not applicable	48	3.313	9.063	0	45
Not at all	37	6.181	11.839	0	50
Somewhat important	4	10.500	17.823	0	37
Important	7	33.714	32.299	0	85
The most important factor	1	33.000	.	33	33
Total	97	7.203	15.314	0	85

It needs to be emphasized that distance in itself can hardly be considered an amenity of a new residential location, and that people rather seek bundles of amenities that may happen to be located at more distant sites. From this perspective, telecommuting cannot be considered the direct cause of an increase in commute distance, although it may well be a facilitator – the factor that makes a more distant location, desired for other reasons, more attainable.

Whether cause or effect, we have seen 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? Naturally, it is also of interest to investigate whether the longer commute distances of telecommuters result in higher VMT. The answer to this question relates not only to telecommuting frequency, but also to commute mode choice. To provide insight into these relationships, the following section explores patterns of telecommuting frequency.

4.2 Telecommuting Frequency

One critical shortcoming of many reports on telecommuting is the aggregation of telecommuters into a single category, regardless of how frequently they telecommute. Our data permit the exploration of frequency patterns in the sample, across the ten-year period under study, and how those frequencies relate to other variables like commute distance and person-miles traveled. A study by Varma *et al.* (1998) on a sample of telecommuters during a period of nine months found that individuals who did not quit telecommuting during that period ("stayers") had a higher mean telecommuting frequency, indicating perhaps that greater intensity accompanies a greater level of commitment. However, among those who did quit telecommuting ("quitters"), those with a higher telecommuting frequency had a tendency to quit sooner, indicating perhaps that greater intensity leads to faster burnout when commitment is lower. Further research into these dynamics would be highly desirable, although since multiple telecommuting episodes are apparently common, the concepts of "stayer" and "quitter" are necessarily relative, as discussed in Section 2.5.

Figure 3 shows the mean telecommuting frequencies for the telecommuting subsample at 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. (In fact, we have already shown in Table 12 of Section 3.5 that, compared to the nationwide proportion of telecommuters in the workforce, the overrepresentation of telecommuters in our sample increases over time, meaning that the telecommuting growth rate shown in Figure 3 is higher than for the nation as a whole.) The trend exhibited by the frequency curve is probably influenced in turn by side effects of the sampling procedure.

Specifically, our first hypothesis for the decay in mean telecommuting frequency over time is that 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. In other words, 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.

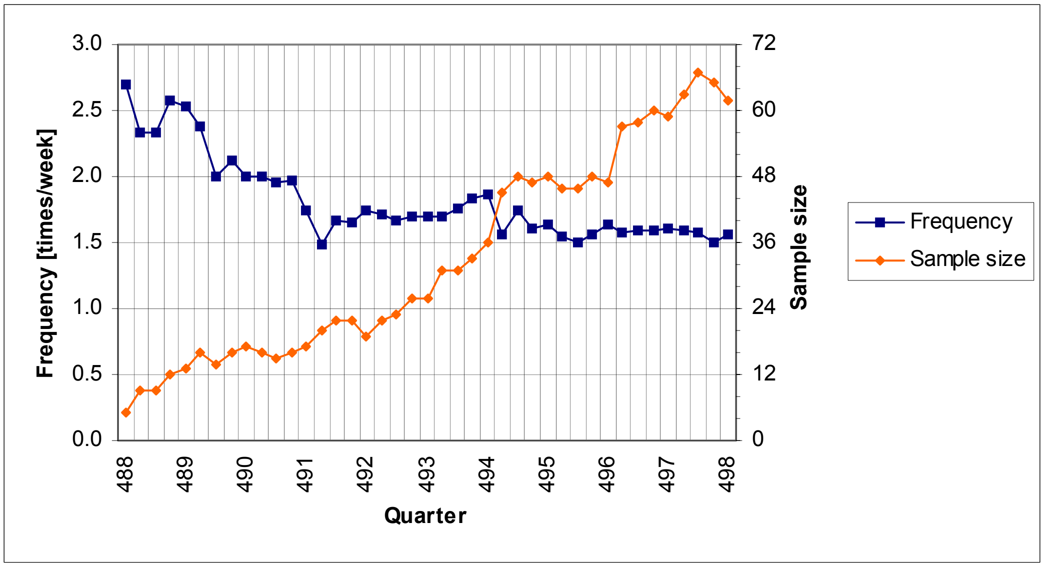

Figure 3. Mean Telecommuting Frequencies

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. Our second 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. In this sample, the effects of the first and second hypotheses are completely confounded. That is, while we confirm below that earlier adopters in our sample tend to telecommute more frequently, we do not know the extent to which this is a genuine behavioral relationship, or a consequence of our sampling procedure.

To test the combined first and second hypotheses, that earlier adopters telecommute more frequently (whether due to a sampling bias or due to greater motivation among earlier adopters), we present the two models shown in Table 16, using two different individual-specific measures of frequency. First, we regressed the telecommuting frequency in the individual's first telecommuting quarter against the natural logarithm of the number of the quarter. The results show that quarter of adoption is significant at the 0.07 level, and with a negative coefficient, meaning that the later telecommuting was adopted by an individual, the lower its initial frequency for that person.

Next, we regressed the average telecommuting frequency across all an individual's telecommuting episodes against the inverse of the number of the initial telecommuting quarter. This variable turns out to be significant at the 0.05 level, and with a positive coefficient, again meaning that the later the quarter of adoption, (the smaller the inverse and) the lower the (average) telecommuting frequency for that individual. Note, however, that these relationships between time of adoption and frequency are relatively weak, with time of adoption accounting for only a few percentage points of the variance in telecommuting frequency as shown by the R^2 measures.

Table 16. Relationship between Telecommuting Frequency and Time of Adoption

Model of Telecommuting Frequency in Quarter of First Adoption				
	B	Beta	T	Sig.
Constant	11.052		6.055	0.000
LN(Number of first telecommuting quarter)	-1.128	-0.187	-1.842	0.069
Adjusted R^2 = 0.025 (R^2 = 0.035), N = 96, F-stat. = 3.394 (p = 0.069)				
Model of Average Telecommuting Frequency across All Episodes				
	B	Beta	T	Sig.
Constant	6.920		10.942	0.000
1/(Number of first telecommuting quarter)	4.836	0.199	1.984	0.050
Adjusted R^2 = 0.030 (R^2 = 0.040), N = 97, F-stat. = 3.936 (p = 0.050)				

Since frequency apparently declines with sample size as well as with elapsed time, it is of interest to see how the decay in telecommuting frequency relates to both variables simultaneously. To that end, we regressed the quarterly mean telecommuting frequency against both time and number of telecommuters. The results, shown in Table 17, indicate that the negative association with sample size shown in Figure 3 is primarily an elapsed-time effect. When elapsed time is controlled for, there is actually a small positive impact of number of telecommuters on average frequency.

Table 17. Regression Model of Quarterly Mean Telecommuting Frequency

	B	t	Sig.
Constant	2.252	44.503	.000
Quarter number	-0.0594	-6.377	.000
Number of telecommuters in the sample	0.0246	4.156	.000

Adjusted R^2 = 0.754 (R^2 = 0.766), N = 41, F-stat. = 62.364 (p = 0.000)

Our third hypothesis for the observed decline in telecommuting frequency 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 not mutually exclusive with the previous one, even for the same individual. It is not practical to test this hypothesis 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 (2002) 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.

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). There does not appear to be a rigorous way to test this hypothesis though, since as discussed earlier, all (total) durations are censored.

While the data were collected at a time when all the respondents were working at one of the six state agencies sampled, not every respondent had always worked at the current organization. Then, the question arises of whether employment at a different organization could have an effect on the observed telecommuting frequency trend. Figure 4 shows the mean telecommuting frequencies for the entire sample (just as in Figure 3) alongside the mean frequencies for individuals while they were working at their current organization. The qualifier "all" in the labels in Figure 4 indicates that the pertinent frequencies or sample sizes correspond to all telecommuting events, regardless of the organization of employment. The decaying trend of the frequencies for the second group is slightly less steep, but in general the trends for the two groups are comparable.

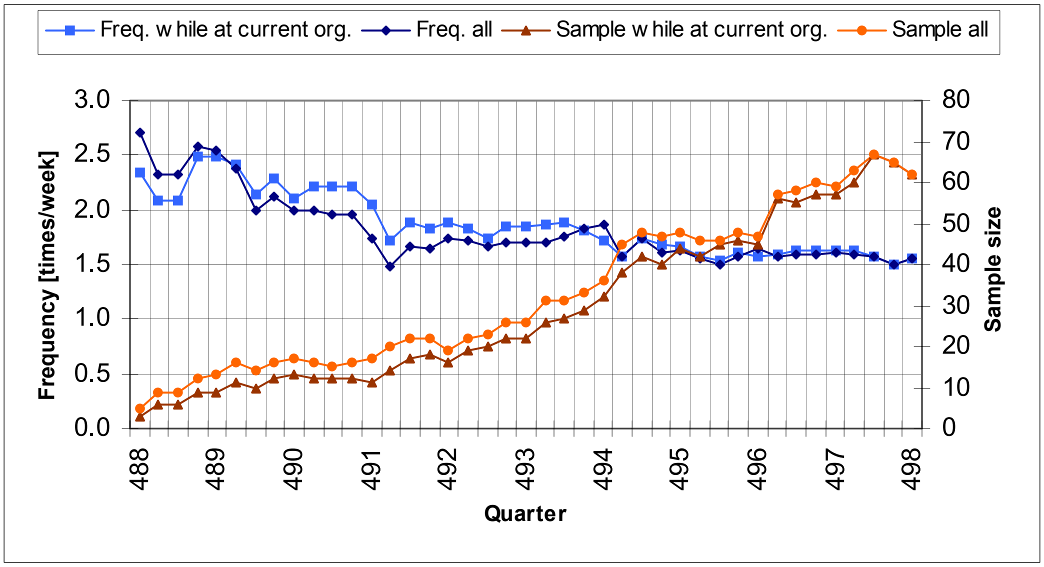

Figure 4. Mean Telecommuting Frequencies while Working at the Present Organization

4.3 Person-Miles Traveled

As described in Section 3.2, 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 Section 4.1 and 4.2 respectively, we now put them together and analyze their combined impact on commute PMT.

Figure 5 presents the per capita commute-related person-miles traveled for the segments of tele-commuters and non-telecommuters at each quarter. Similar to Figure 1 for the one-way commute length, there is a general upward trend that largely flattens out in the last three years of the study period. The plot in Figure 5 is bumpier than the one in Figure 1, generally showing a periodic pattern with a low point in the first quarter of each year. This pattern is largely an artifact of variations in the number of working days per quarter. To control for this factor, Figure 6 plots the mean *daily* per-capita PMT on a quarterly basis, which shows a much smoother trend, at least for non-telecommuters.

The more erratic nature of the plot for the telecommuters corresponds to the strong fluctuations in mean one-way commute lengths for telecommuters shown in Figure 2. That figure illuminates why the mean daily per capita PMT for telecommuters dips during 1992, despite the fact that especially the first quarter corresponds to a low in mean telecommuting frequency, as shown in Figure 3: the reduction in telecommuting frequency is more than compensated for by the reduction in one-way commute length. The first two and the fourth quarters of 1992 are the only quarters during the study period 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 2 and discussed in Section 4.1, 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.

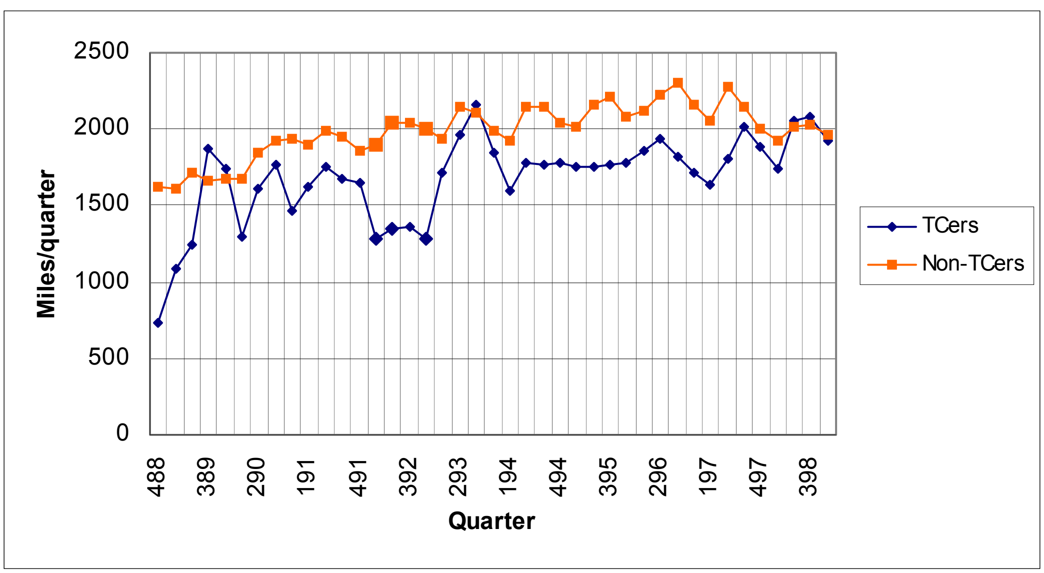

Figure 5. Mean Per-Capita Commute Person-Miles Traveled for Telecommuters and Non-Telecommuters

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 from work, relative to non-telecommuters) while telecommuting frequencies have stabilized, telecommuters' per-capita commute PMT will quickly 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 2.1. 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.

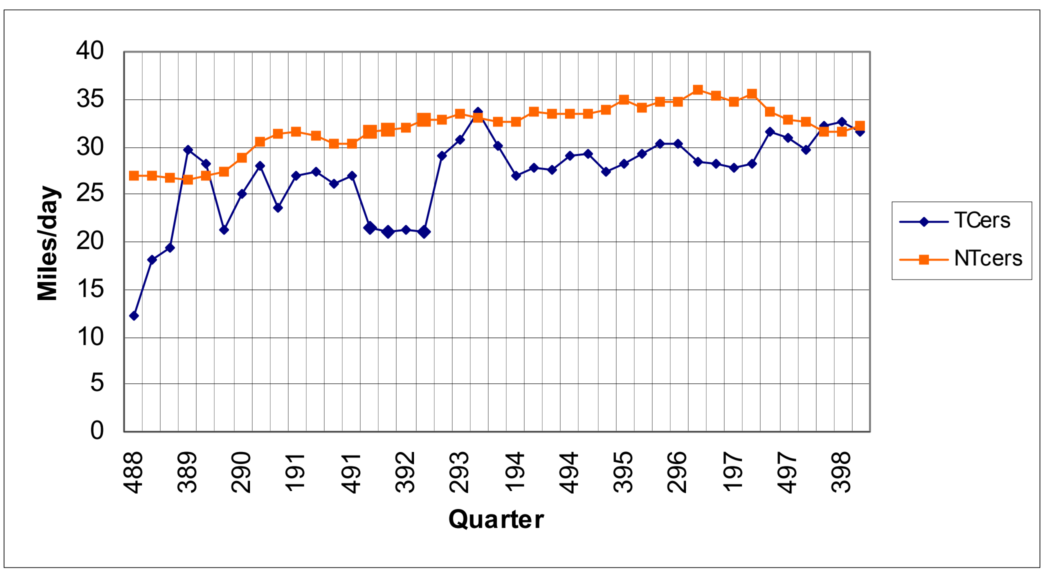

Figure 6. Mean Per-Capita Daily Commute Person-Miles Traveled for Telecommuters and Non-Telecommuters

4.4 Vehicle-Miles Traveled

Means were also estimated for the daily VMT done driving alone (VMT_L, as defined in Section 3.3) and VMT done by any combination of modes that included a personal vehicle (VMT_U). Figure 7 shows the time series for the mean VMTs across the sample as a whole corresponding to these two definitions, together with their respective sample sizes at each quarter. As expected, the sample sizes for the more liberal definition of VMT (VMT_U, any commute involving a personal vehicle) are considerably larger, but the basic trends are similar for both curves.

Figure 8 presents the mean per capita commute-related miles traveled at each quarter for the segments of telecommuters and non-telecommuters that reported "drive alone" as their commute mode (VMT_L). Figure 9, on the other hand, presents the same information but for those respondents who reported any commute mode combination that included a personal vehicle (VMT_U). As in the plot of PMT in the preceding section, the trends corresponding to the telecommuting segments are more erratic than the ones of non-telecommuters. The two figures however exhibit different patterns in terms of the differences between the two segments. Those quarters with statistically significant differences ($p < 0.05$) in VMT for telecommuters and non-telecommuters are highlighted with bigger markers. For VMT_L, these significant differences correspond to the four quarters of 1995, the first and third quarters of 1996, the first two quarters of 1997, and the first quarter of 1998, while for VMT_U they correspond to the four quarters of 1992, in much closer resemblance to what was found for differences in PMT (see Figure 5). This is not unexpected, since VMT_U is closer to PMT than VMT_L is.

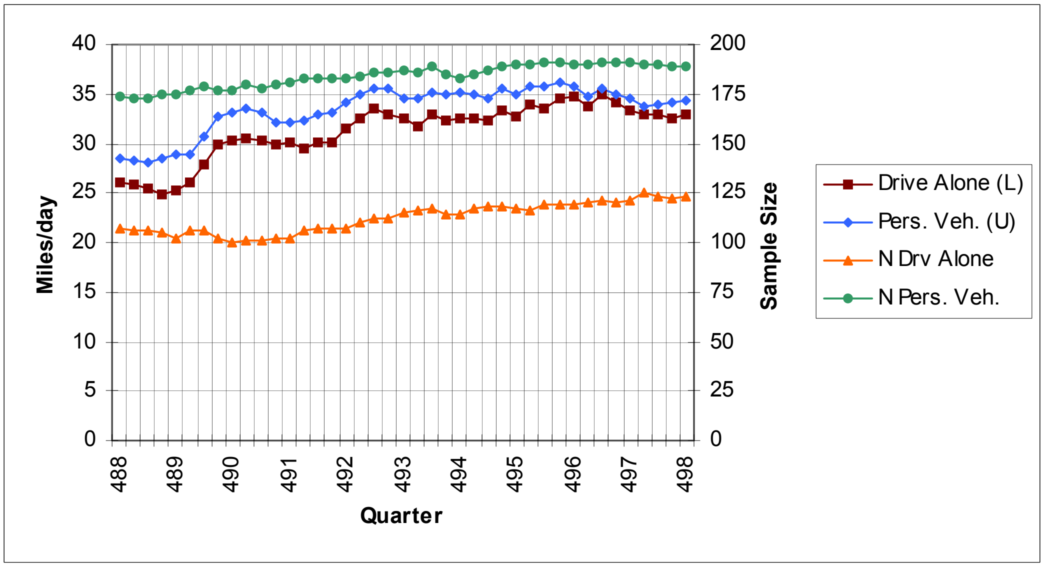

Figure 7. Mean Daily Commute VMT by Driving Alone and by any Mode Combination that Includes a Personal Vehicle

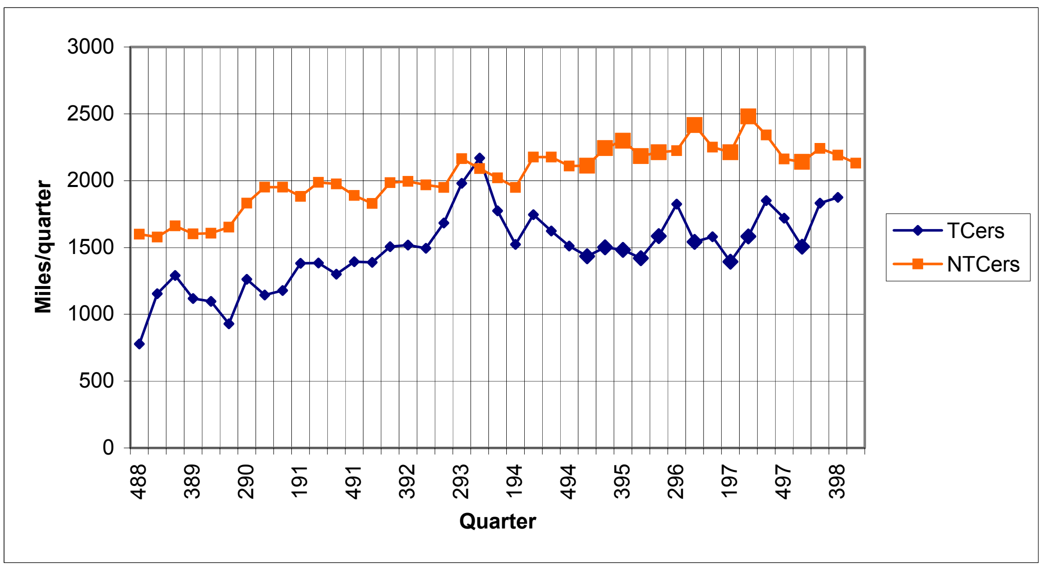

Figure 8. Mean Per-Capita Commute VMT$_L$ for Telecommuters and Non-Telecommuters

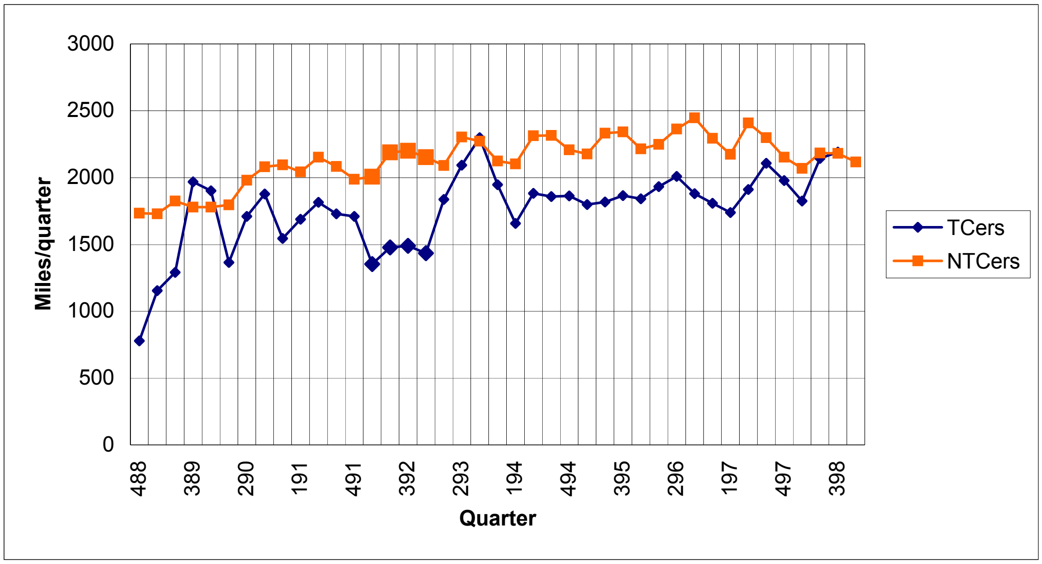

Figure 9. Mean Per-Capita Commute VMT_U for Telecommuters and Non-Telecommuters

To filter the effect of seasonal variations in number of working days out of these curves, plots for the *daily* VMT_L and VMT_U are presented in Figures 10 and 11 respectively. In all of Figures 8-11, as for PMT, the VMT for telecommuters generally lies below that for non-telecommuters, and is always lower in quarters where the difference is statistically significant.

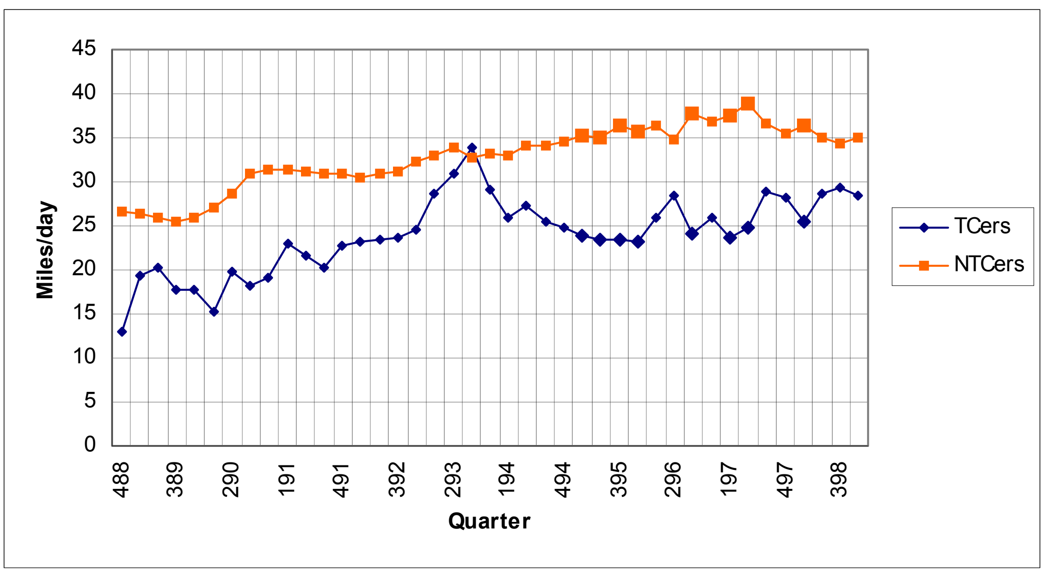

Figure 10. Mean Daily Commute VMT_L for Telecommuters and Non-Telecommuters

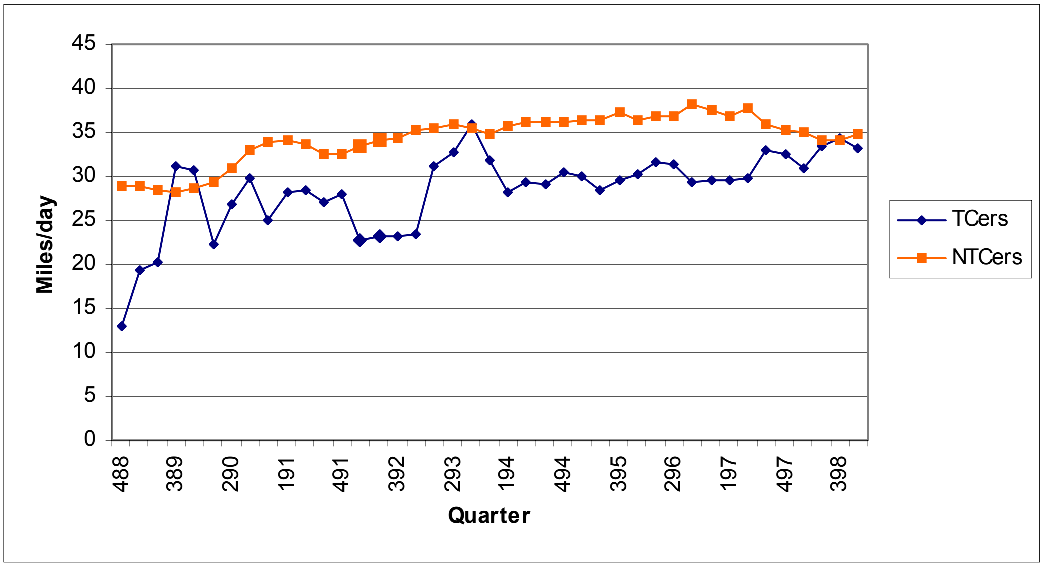

Figure 11. Mean Daily Commute VMT_U for Telecommuters and Non-Telecommuters

4.5 Telecommuters' Contribution to Overall PMT and VMT

Figures 6, 10, and 11 illustrate that daily per-capita commute PMT and VMT are 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 and VMT 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 Section 3.5. As background, Figure 12 presents the aggregate quarterly PMT for the two segments, estimated with the weighted number of telecommuters and non-telecommuters, shown also in the figure.

Figure 13 compares the proportion of total commute PMT 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 6, telecommuters' proportion of total commute PMT is lower than their proportion in the workforce for all but five quarters, but Figure 13 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 Table 12). 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.

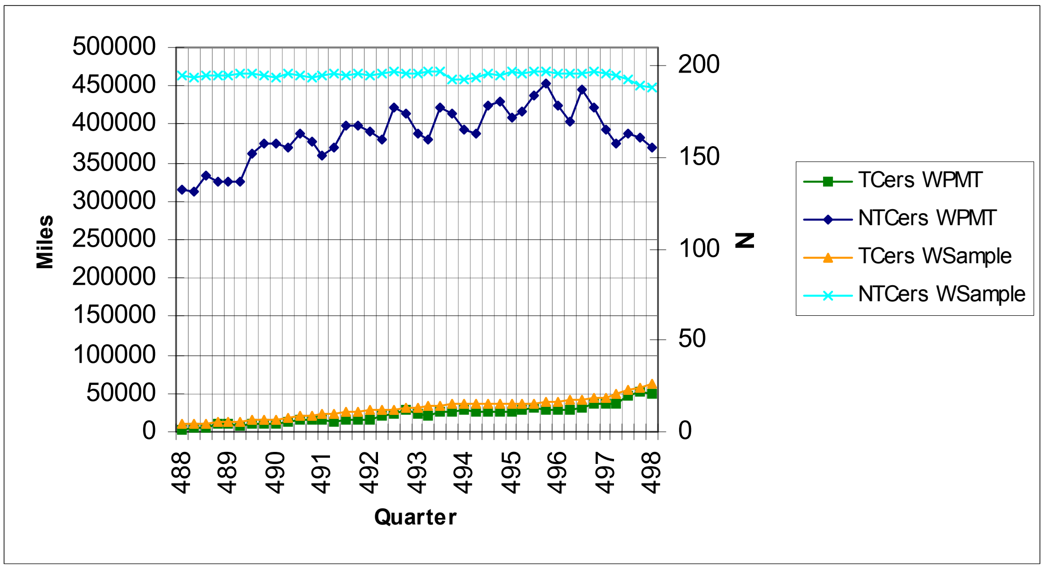

Figure 12. Aggregate Weighted Commute PMT and Segment Sizes of Telecommuters and Non-Telecommuters

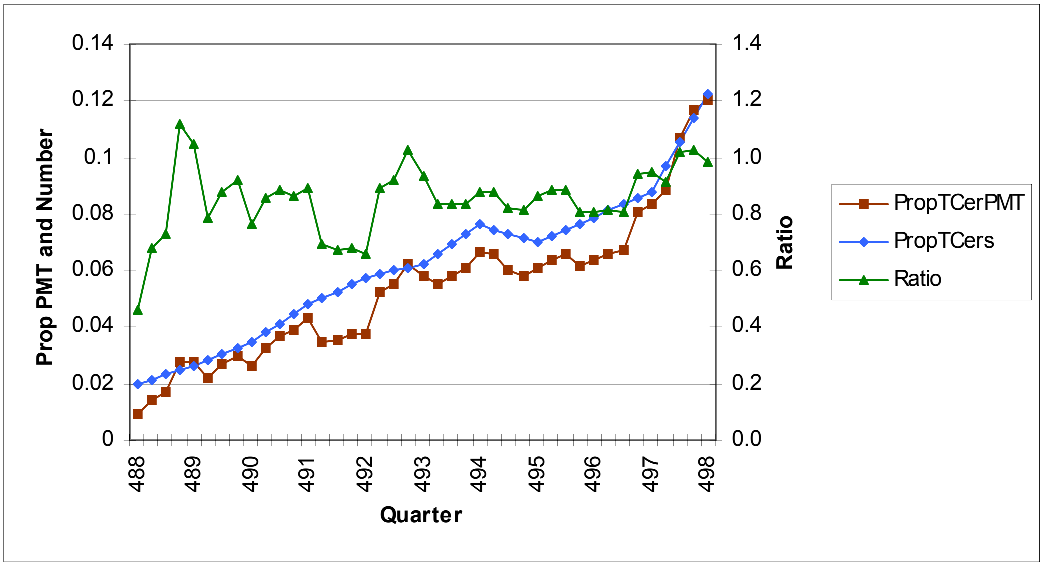

Figure 13. Proportion of Total PMT Relative to Proportion in the Workforce for Telecommuters

Figure 14 shows a similar analysis, this time using the commute-related VMT_L (vehicle-miles traveled driving alone), instead of PMT. PropTCerVMTL is the proportion of commuting VMT accounted for by the weighted sample of telecommuters. It takes its minimal value of 0.010 in the first quarter, and its maximal value of 0.100 in the last quarter. The ratio of PropTCerVMTL to PropTCers reaches a value of one only in the fourth quarter of 1993 (1.04), and shows that on average, the contribution of telecommuters to commute VMT_L is only 74% of their proportion in the workforce. In contrast to the case of commute PMT, Figure 14 shows that the proportion of VMT_L accounted for by telecommuters remains clearly lower than their proportion in the workforce (with the exception just mentioned) even toward the end of the study period.

A similar analysis can be conducted for our upper-limit estimate of vehicle-miles traveled, VMT_U. As shown in Figure 15, the ratio of PropTCerVMTU to PropTCers reaches a value of one in four quarters: the third and fourth of 1989, the third of 1993, and the third of 1998. Overall, the proportion of VMT_U by telecommuters is closer to the proportion of telecommuters in the workforce, with the average of the ratio equal to 0.84. Thus, even our conservative measure of telecommuters' VMT remains mostly below the proportion of telecommuters in the workforce, which may lend support to telecommuting as a strategy to reduce commute vehicle-miles traveled. However, it should be noted that the trends of both ratios in Figures 14 and 15, although erratic, are essentially increasing in time. If these trends continue to increase, they could be expected eventually to cross and remain above the critical value of one, which could be interpreted as an undesired effect of telecommuting. Whether such an interpretation was valid or not would depend on the direction of causality between telecommuting adoption and commute distance, as discussed throughout this report.

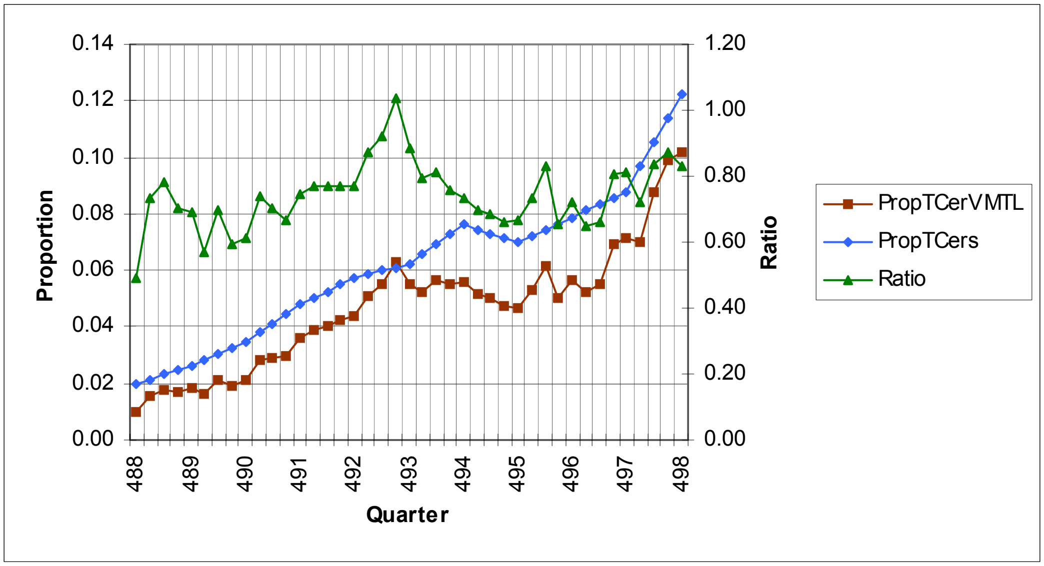

Figure 14. Proportion of Total VMT_L Relative to Proportion in the Workforce for Telecommuters

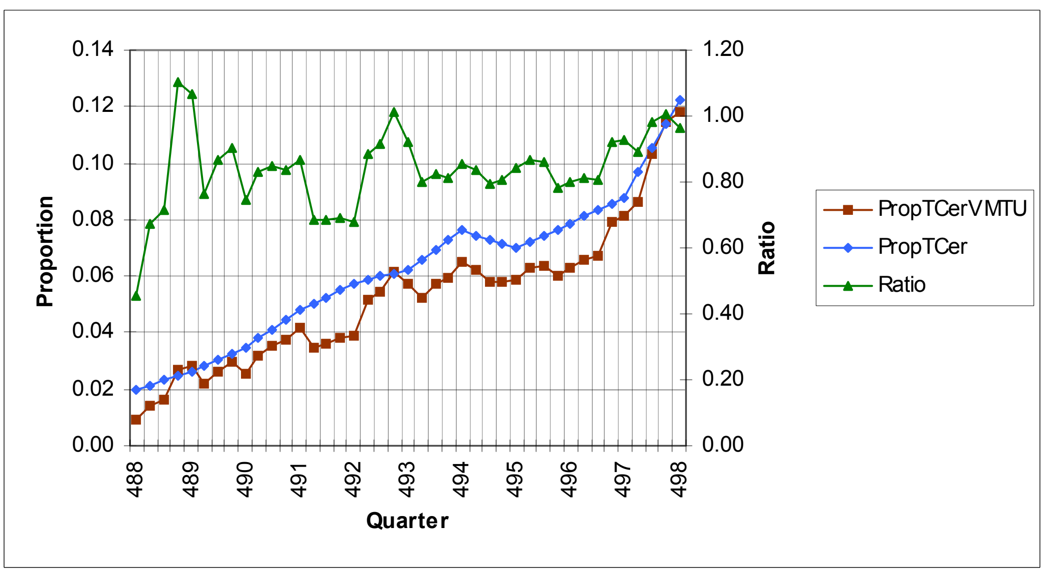

Figure 15. Proportion of Total VMT_U Relative to Proportion in the Workforce for Telecommuters

Having seen that telecommuters' actual commute PMT is lower than non-telecommuters', it is of interest to examine what their commute PMT *would be* if they were not telecommuting. In Figure 16 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. PropHypoTCerPMT 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 in the first quarter and 0.172 in the last quarter. Figure 16 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 2, 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 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.

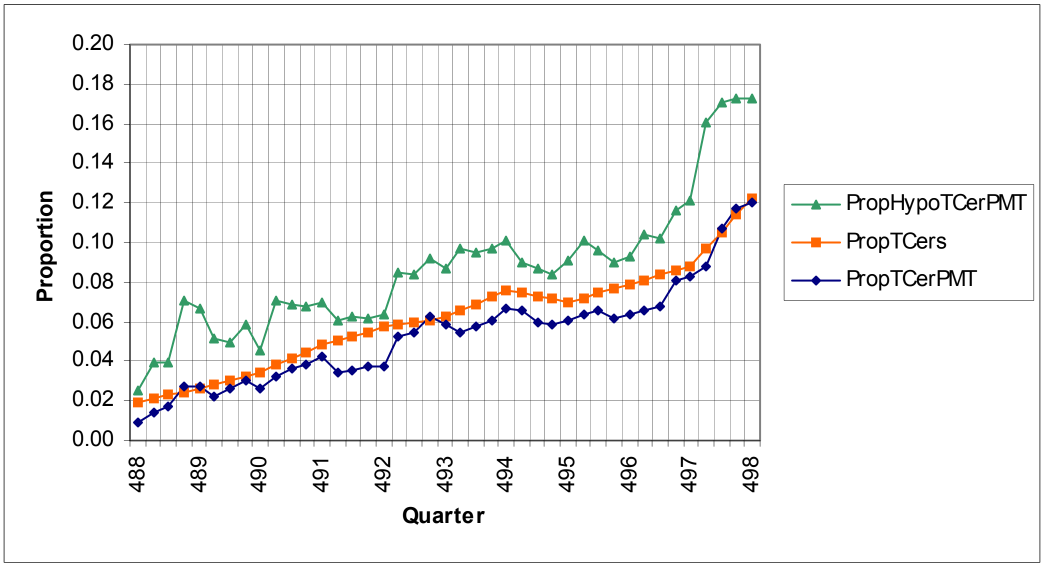

Figure 16. Comparison of Actual and Hypothetical (if Not Telecommuting) PMT of Telecommuters, Relative to Their Workforce Proportion

5. CONCLUSIONS

In this study we investigate 10-year retrospective data on the telecommuting engagement, and residential location of a sample of 218 employees of six California State agencies with established telework programs since 1988. The focus of the study was, through the understanding of telecommuting behavior and residential location, to analyze the impacts of those decisions on commute person-miles traveled and vehicle-miles traveled.

Our results provide consistent evidence that, while telecommuters on average live farther away from their workplace, they telecommute with a frequency such that their mean commute PMT and VMT are lower than for non-telecommuters. The differences in commute lengths are however found to be statistically significant more often than the difference in PMT or VMT.

In order to be able to assess the social desirability of telecommuting policies we also need to understand not only how telecommuting adoption depends on commute distance, but also to what extent the ability to telecommute may be a facilitator of residential relocations farther away from work. While this report provides no definite results on this respect, it does present some evidence suggesting that, in our sample, net moves to more distant locations tended to take place before the first telecommuting event. It was however found that those for whom telecommuting was an important factor in their last residential relocation moved significantly farther away from their workplace, thus suggesting that the ability to telecommute *can* facilitate the increase in commute distances. It is important to notice that telecommuting was an important factor in relocation only for a small fraction of movers, which indicates that residential relocations are dominated by factors other than the ability to telecommute.

We have found that mean telecommuting frequencies in our sample significantly decay both with time (converging to just over 1.5 times per week), and with the number of telecommuters in the sample. It is difficult to ascertain the reasons for the decay in telecommuting frequencies from our data, but four hypotheses were formulated. While high-frequency telecommuters are found at any stage during the study period, lower-frequency telecommuters are much less abundant in the early quarters, thus boosting the mean telecommuting frequency for those quarters. It is difficult to be certain about the reasons behind this lack of lower-frequency telecommuters in the early stages: it might represent an artifact of the sampling procedure or might equally well be representative of the true distribution of frequencies over time.

An encouraging result in support of telecommuting as a transportation demand management tool is that, while adopters of telecommuting tend to commute longer distances, their proportion of the total commute PMT of the workforce is found to be lower than telecommuters' proportion of the workforce for most of the quarters analyzed. This suggests that the implementation of telecommuting programs results in a net reduction in total commute PMT. More importantly, similar results are found for commute-related VMT: the proportion of VMT (based on those individuals that reported commuting by driving alone) is clearly lower than the proportion of telecommuters in the workforce for all but one of the quarters in the study period. This result provides evidence in support of telecommuting as an effective transportation demand management tool, and as a policy mechanism to reduce tailpipe emissions from automobiles, at least during the commuting hours and along commuting corridors.

It should be emphasized again that in this report 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 with absolute certainty 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 provide a definitive assessment of 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 report.

Future research could collect data on possible determinants of telecommuting adoption and residential relocation, such as income, education, household size, and ability to telework, for every quarter of the study period. This would allow the control of potential third-party correlations among telecommuting adoption, telecommuting frequency, and commute length.

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