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Abstract

Using retrospective data collected from a survey of more than 200 State of California workers, including current, former, and non-telecommuters, this study analyzes the relationship between telecommuting and commute time, distance, and speed over the ten-year period from 1988 to 1998. We find that telecommuters consistently live farther from work (in terms of time and distance) compared to former and future telecommuters. These longer one-way distances are ameliorated, however, by telecommuters traveling at higher speeds and commuting less frequently than their counterparts, with an end result of telecommuters commuting fewer person-miles and person-minutes, on average. About 70% of the commute time savings can be attributed to the faster speeds, with the remainder due to the lower distances traveled. Interestingly, in the aggregate, those who telecommute at some point in the ten-year period average slightly (2.6%) more commute person-miles traveled (although 4.4% less time) over the decade (even with the reductions offered by telecommuting) than those who do not telecommute at all. This finding suggests either that telecommuting is at best an ineffective travel reduction policy (i.e. those who engage in it do not travel any less) or that telecommuting disproportionately attracts those who would otherwise commute even more (making it an effective tool). A companion study addresses this question and finds that the latter explanation is the stronger one.

1. Introduction

Telecommuting has found a place on the menu of policies designed to reduce travel. Various studies (see, e.g., Hamer, *et al.*, 1991; Mokhtarian, *et al.*, 1995) suggest that telecommuters (on days they telecommute) do, in fact, travel less than non-telecommuters. This evidence has encouraged lawmakers to enact policies that encourage telecommuting. For example, United States bill H.R. 4475 (Sec. 359), signed into law on October 23, 2000, states that “each executive agency [of the Federal Government] shall establish a policy under which eligible employees of the agency may participate in telecommuting to the maximum extent possible without diminished employee performance.”

Unfortunately, nearly all of the empirical studies on which the positive reputation of telecommuting is based have focused on the short-term impacts of telecommuting, typically within one to two years of individual or organizational adoption. However, a number of researchers (e.g., Janelle, 1986) have raised the issue that the ability to telecommute may prompt workers to move farther away from their jobs to cheaper or higher-amenity residential locations, resulting in a longer, though less frequent, commute. The total commute distance and time traveled in such cases may actually be higher after telecommuting than before. If such cases are quite common, then the degree to which telecommuting is promoted as a travel-reduction strategy should be re-examined. Hence, we need information on the nature of the longer-term relationships among telecommuting, one-way commute length, and commute frequency in order to inform transportation policies relating to telecommuting.

This paper builds upon two previous studies, each of which uses the same cross-sectional survey of current, former, and non-telecommuters working in various State of California agencies. The survey targeted agencies that have continued telecommuting programs since the late 1980's and retrospectively inquired about residential and job relocations, commute characteristics (time, length, and mode), and telecommuting engagement over a ten-year period. Mokhtarian, *et al.* (2004) used this data to compare, quarter by quarter, the one-way commute length and average daily person-miles traveled of telecommuters (those regularly telecommuting during the three-month quarter) and non-telecommuters (those not regularly telecommuting). The authors found that although telecommuters do live farther from their workplaces than non-telecommuters, they commute infrequently enough to travel less, on average. Ory and Mokhtarian (2004) directly examined the issue of causality in the relationship

between telecommuting and residential/job relocations, asking: does the ability to telecommute encourage more distant relocations, or do more distant relocations (caused by reasons other than telecommuting) encourage telecommuting? The authors found more evidence in support of the latter argument, that distant relocations are encouraging telecommuting. Mokhtarian *et al.* (2004) did not address the issue of causality, concluding that because telecommuters tend to travel less (for commuting) than non-telecommuters, telecommuting can be viewed positively regardless of the direction of causality.

The current study first extends the work of Mokhtarian *et al.* (2004) by re-visiting the analysis of commute length and person-miles traveled, here using a different baseline market segment. The earlier study compared the behavior of those engaged in a telecommuting episode in a given three-month quarter of the study decade, with those not engaged during that quarter. Thus, the composition of each subsample (telecommuters and non-telecommuters) was quite volatile, with telecommuters changing their telecommuting status far more often than their residential or job location. The current study adopts a different definition found in Ory and Mokhtarian (2004). Specifically, we divide the sample at each quarter into three groups rather than two: those regularly telecommuting at the time (Current), those who telecommute regularly at some point during the decade but are not doing so that quarter (Former/Future), and those who do not telecommute at all during the study period (Never). This permits multiple comparisons of interest. For example, comparing the Former/Future telecommuters with the Never telecommuters illuminates to what extent people who ultimately adopt telecommuting may differ from those who never do, while comparing Current to Former/Future telecommuters is an appropriate way to assess the impacts of telecommuting on the group of eventual adopters. In any given quarter, we treat the Former/Future telecommuters as roughly representing the counterfactual conditions for telecommuters had they not been telecommuting¹.

In a manner similar to the comparison of commute length and person-miles traveled discussed above, a completely new analysis of commute duration and person-minutes traveled is presented. Though distance measures such as person- and vehicle-miles traveled are more often used by transportation planners (probably because regional travel models can more

¹ This assumption would be stronger if Current and Former/Future telecommuters had similar one-way commute lengths and durations, whereas Figures 1 and 3 show that Current telecommuters have longer commutes. Nevertheless, this arguably makes the finding of Figures 6 and 7, that Current telecommuters' overall commute travel is lower than that of Former/Future telecommuters, even more compelling.

accurately predict these quantities), time and speed measures may be more important to the travelers themselves, especially over time (i.e. with a static home-job combination, an individual may suffer from increased congestion – a change in commute duration – even without a change in commute distance). The differences found in the comparisons of time and distance led us to examine commute speed among telecommuters and non-telecommuters, which, in turn, led to the examination of commute mode (a primary determinant of speed). In time, distance, speed, and mode measures, we have a relatively complete picture of the commute characteristics of telecommuters and a comparable control group over a ten-year period. The impact of telecommuting on commuting can then be assessed using these measures.

Granted that, in the aggregate, commute distance and time are lower for Current telecommuters than for Non-telecommuters, a devil's advocate might ask several further questions:

- Could this result be due to large savings for just a minority of telecommuters? In other words, on an individual basis, for what proportion of telecommuters is the aggregate result true, i.e. for what proportion of telecommuters is commute travel actually reduced during telecommuting episodes?
- Are telecommuters still “commute villains” overall? Given that telecommuters, even during non-telecommuting episodes, live farther from work than Never telecommuters, are the commute reductions they experience during their telecommuting episodes sufficient to compensate for the “surplus” commuting they engage in during non-telecommuting episodes? i.e., over the ten-year study period involving both telecommuting and non-telecommuting episodes, do those who telecommute commute more, or less, than those who never telecommute? And again, for how many telecommuters does the “average” result hold – is it “typical”, or skewed by a few outliers?

Answering these questions comprises additional new analyses of this paper.

The organization of the remainder of this paper is as follows. In Section 2 we describe the empirical context and the available data, and in Section 3 we discuss the definitions of three important variables in the study: commute person-miles and -minutes traveled and quarterly telecommuter status. In Sections 4, 5, and 6 we present the main results associated with each of the key variables analyzed here: one-way commute duration and length; commute speed and travel mode; and average daily two-way commute person-miles and person-minutes. Section 7 offers a summary and discussion of the findings.

2. Empirical Setting and Available Data

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

To gather the desired data, a 16-page self-administered survey was designed and distributed in November 1998 to employees of the following six California state agencies: California Energy Commission, Department of Personnel Administration, Franchise Tax Board, California Youth Authority, Department of Motor Vehicles, and Department of Social Services. Each of these agencies has kept their telecommuting programs active since the pilot implementation in 1988.

The survey was distributed to those who responded to an initial broadcast email message, sent to key divisions or groups within each agency. The message stressed the need for participation from telecommuters, non-telecommuters, and former telecommuters, and offered a drawing for cash prizes of \$250, \$150, and \$100. Due to the intended approach of enriching the sample with telecommuters, the data are not representative of any general population – i.e., the ratio of telecommuters to non-telecommuters in the sample is higher than in the population as a whole. However, to the extent that each subsample is representative of the population from which it is drawn, comparisons of average behavior across subsamples will be valid even if the share of the sample in each group is not itself representative.

Thus, more important, and independent from the representativeness of the telecommuter/non-telecommuter ratio, is the question of whether the telecommuters in the sample are representative of the general population of telecommuters. Unfortunately, there are no reliable data on the demographics and other characteristics of telecommuters in the population, making any comparison of our sample (in terms of gender, income, etc) to the population of telecommuters impossible. 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 who remember telecommuting 10 years ago well enough to report it on a survey a decade later may have had more extreme circumstances than the typical

telecommuter of that time (see Mokhtarian, *et al.*, 2004 for further discussion of this issue). An additional potential for bias is presented by the sample being composed solely of state employees. The attitudes, opinions, and behaviors of state employees may differ in a systematic, or biased, way from those employed in the private sector (though no particular hypothesis regarding the current analysis presents itself). Important demographic characteristics of the sample are included in Table 1.

The survey instrument contained two 10-year timelines (segmented into quarter-years) that captured the key data for this analysis. On the first timeline, current and former telecommuters indicated all the periods of time during which they telecommuted regularly, the frequency with which they telecommuted during each of those periods, and reasons for quitting or changing frequency in each case. ("Regular" telecommuting was defined as "at least two days a month on average, for at least three consecutive months"). On the second timeline, all respondents recorded their job and residential relocations that took place during the 10-year span and, for each job-residence location pair (including the pair at the beginning of the 10-year period), indicated their one-way commute length, duration, and primary mode. The two timelines were separated by three pages, so although respondents could have made a conscious effort to "match them up", they were not particularly led to do so by the survey design. The current study focuses on the information available from the two timelines; preliminary analysis of other parts of the survey can be found in Gertz and Mokhtarian (1999).

This study analyzes the 218 individuals having essentially complete timeline responses. Of these 218 responses, 97 people telecommuted at some point during the study period and 121 never telecommuted during the ten-year period; 62 people were telecommuting at the time of data collection.

Table 1: Key Characteristics of the Sample

	Total sample	Current telecommuters (final quarter)	Former telecommuters	Never telecommuters
Categorical/ordinal variables: Frequency (%)				
Gender				
Female	150 (68.8)	45 (72.6)	26 (74.3)	79 (65.3)
Male	68 (31.2)	17 (27.4)	9 (25.7)	42 (34.7)
<i>Total</i>	218 (100.0)	62 (100.0)	35 (100.0)	121 (100.0)
Occupation				
Manager/Administrator	29 (13.3)	6 (9.7)	6 (17.1)	17 (14.0)
Professional/Technical	161 (73.9)	53 (85.5)	24 (68.6)	84 (69.4)
Administrative support	23 (10.6)	2 (3.2)	5 (14.3)	16 (13.2)
Other	3 (1.4)	1 (1.6)	- (-)	2 (1.7)
<i>Total</i>	216 (99.1)	62 (100.0)	35 (100.0)	119 (98.3)
Education				
Some grade or high school	2 (.9)	- (-)	1 (2.9)	1 (.8)
High school graduate	3 (1.4)	- (-)	- (-)	3 (2.5)
Some college	86 (39.4)	20 (32.3)	14 (40.0)	51 (43.0)
Four-year college degree	62 (28.4)	22 (35.5)	6 (17.1)	34 (28.1)
Some graduate school	32 (14.7)	10 (16.1)	5 (14.3)	17 (14.0)
Completed graduate degree	31 (14.2)	10 (16.1)	8 (22.9)	13 (10.7)
<i>Total</i>	216 (99.1)	62 (100.0)	34 (97.1)	120 (99.2)
Annual personal income				
Less than \$15,000	3 (1.4)	1 (1.6)	- (-)	2 (1.7)
\$15,000 to 34,999	40 (18.3)	5 (8.1)	4 (11.4)	31 (25.6)
\$35,000 to 54,999	93 (42.7)	27 (43.5)	21 (60.0)	45 (37.2)
\$55,000 to 74,999	49 (22.5)	18 (29.0)	3 (8.6)	28 (23.1)
\$75,000 to 94,999	18 (8.3)	5 (8.1)	4 (11.4)	9 (7.4)
\$95,000 or more	15 (6.9)	6 (9.7)	3 (8.6)	6 (5.0)
<i>Total</i>	218 (100.0)	62 (100.0)	35 (100.0)	121 (100.0)
Work schedule type				
Part time	14 (6.5)	6 (9.8)	2 (5.7)	6 (5.0)
Conventional	78 (35.9)	13 (21.3)	16 (45.7)	49 (40.5)
Flextime	58 (26.7)	18 (29.5)	9 (25.7)	31 (25.6)
Compressed work week	57 (26.3)	22 (36.1)	8 (22.9)	27 (22.3)
Other	10 (4.6)	2 (3.3)	0 (0.0)	8 (6.6)
<i>Total</i>	217 (100.0)	61 (100.0)	35 (100.0)	121 (100.0)
Residential area type				
Large city	91 (41.7)	21 (33.9)	15 (42.9)	55 (45.5)
Suburb of large city	59 (27.1)	18 (29.0)	11 (31.4)	30 (24.8)
Medium-size city	25 (11.5)	10 (16.1)	5 (14.3)	10 (8.3)
Small city	17 (7.8)	2 (3.2)	3 (8.6)	12 (9.9)
Town or village	6 (2.8)	1 (1.6)	- (-)	5 (4.1)
Countryside	18 (8.3)	9 (14.5)	1 (2.9)	8 (6.6)
<i>Total</i>	216 (99.1)	61 (98.4)	35 (100.0)	120 (99.2)
Continuous variables: Mean (s.d., N)				
Age	43.2 (8.7, 217)	43.2 (8.6, 62)	44.7 (8.9, 35)	42.8 (8.8, 120)
Household size	2.8 (1.4, 218)	2.7 (1.3, 62)	3.0 (1.1, 35)	2.9 (1.4, 121)

Source: Mokhtarian, *et al.* (2004)

3. Person-miles/-minutes Traveled and Telecommuter Definitions

The primary focus of this paper is on the joint relationships between telecommuting and commute time, distance, and speed. The analyses of person-miles/-minutes traveled are isolated to the commute to and from work and do not include other trip purposes. Group-specific averages for each measure (commute length, duration, speed, mode share, person-miles traveled and person-minutes traveled) are computed for each quarter-year during the ten-year time frame of the retrospective survey. To differentiate between the one-way commute distance/time and the average daily two-way person-miles/-minutes traveled (which considers telecommuting frequency), the following terminology will be used throughout the paper: the one-way, single-trip commute distance will be referred to as **commute length**; the one-way, single-trip commute time will be referred to as **commute duration**; average daily two-way person-miles traveled as **commute distance**; and average daily two-way person-minutes traveled as **commute time**.

The two-way average daily person-miles (commute distance) and -minutes (commute time) traveled are computed using the following equation:

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

where T_{iq} is the reported one-way commute length or duration for person i in quarter q , wd_q is the number of working days that apply to California state employees in quarter q (number of weekdays less the number of official state holidays), and tcf_{iq} is the telecommuting frequency (that is, the number of days person i telecommutes in quarter q). So, the commute distance and time are obtained by deflating twice the one-way length and duration, respectively, by a factor equal to the proportion of working days on which the commute is made.

For many reasons, the above equation is only an approximation of the actual commute amounts. First, the equation assumes all individuals travel to their place of employment once on every official workday. As such, the computation overestimates travel amounts for those who take sick days and those who work a part-time or compressed schedule. Conversely, it underestimates travel for those who make multiple trips to the office during the week and who make any trips during the weekend. Second, the equation assumes a direct trip from home to work and does not consider side trips (i.e. trip chaining); the respondents may or may not have included these side trips into their reported one-way length and duration responses. It may be

that certain side trips are only made on the commute to and from work, and on days a worker telecommutes, these trips may be made to more or less distant locations. Third, the relatively coarse nature of the data, both in asking the respondents their commute length and duration directly, which leads to round-off error to the nearest five minutes, and the arbitrary quarter-year timeline segmentation, which sets artificial boundaries in the data, reduces the precision of the computations.

When assessing the impact of telecommuting in the analysis, the rules for labeling each individual, or more specifically labeling each individual in each quarter-year time period, as a telecommuter or a non-telecommuter are important. The survey instrument defined telecommuting simply as "...working from home (or a nearby center) instead of going to your normal workplace at the usual time." The respondents were instructed to indicate on the timeline the quarters in which they telecommuted "regularly" (as defined in Section 2)

Each individual in the sample is defined as a telecommuter (or not) in five different ways in each quarter-year, as follows:

- **Current telecommuter:** individual telecommuting regularly during the current time period;
- **Non-telecommuter:** individual NOT telecommuting regularly during the current time period;
- **Ever telecommuter:** individual who telecommutes regularly at any point during the ten-year data collection period (holds at the individual level, with no variation by quarter);
- **Never telecommuter:** individual who does NOT telecommute regularly at any point during the ten-year data collection period (also holds at the individual level);
- **Former/Future telecommuter:** Ever telecommuter who is NOT regularly telecommuting during the current time period.

Thus, at any given quarter the sample can be partitioned into Current and Non-telecommuters (with Non-telecommuters further divided into Former/Futures and Nevers), or, independent of quarter, into Ever and Never telecommuters (with Evers further partitioned into Currents and Former/Futures at any given quarter).

Due to the bounded time frame in which data is collected, the Former/Future and Ever/Never definitions will erroneously classify individuals when their past or future telecommuting engagement falls outside the ten-year period of the survey instrument. Also, the arbitrary nature of the definition of “regular” telecommuting will impact the results. However, given the fact that one’s telecommuting status is always a “moving target”, and that any duration and frequency requirements will be arbitrary, these definitions are considered adequate for the purposes of this study.

4. One-way Commute Length and Duration

As mentioned previously, the one-way commute distance, as reported by the survey respondents, is referred to as **commute length**, and the corresponding one-way commute time is referred to as **commute duration**. In this section, the commute length and duration are examined. The purpose of the investigation is to determine whether or not telecommuters are, in fact, living farther from their jobs than non-telecommuters, as has been found elsewhere (see, e.g., Mokhtarian, *et al.*, 1995; Gareis, 2003). Such an investigation constitutes a necessary first step toward addressing the concern that telecommuting may be encouraging more distant relocation patterns: if telecommuters do not live farther from work than non-telecommuters, they probably will not commute more and the remaining analyses are, arguably, moot.

The commute length results for Current, Former/Future, and Never telecommuters are shown in Figure 1. The sample sizes for each of these groups for each quarter are shown in Figure 2; these sample sizes hold approximately – to the extent the respondent gave valid time, distance and telecommuting frequency responses – for all the remaining figures. The slight rises in the sample sizes of both the Ever and Never groups over time reflect the phased entry of some respondents into the workforce over the ten-year study period. As discussed in Mokhtarian, *et al.* (2004), the one-way commute lengths of our sample are longer than national averages, probably because of the relatively large concentration of higher incomes and white-collar workers in the sample; the same assumptions likely hold for commute durations as well.

Figure 1 indicates a general trend of Current telecommuters living farther from work than Former/Future telecommuters. These differences are statistically significant (shown with larger markers on the Current telecommuters’ series) in nine quarters, including the last five time intervals captured by the survey. Figure 1 also indicates a general trend of Former/Future telecommuters living farther away from work than Never telecommuters, though not statistically

significantly farther in any quarter. This latter finding makes sense in that those who live farther from work may be more likely to choose to telecommute in the future, or more likely to have recently engaged in a telecommuting episode, than those who live closer to work. Interestingly, during the last three time intervals, when the majority of Former/Future telecommuters are of the former variety, the Former/Future segment lives, on average, closer to work than Never telecommuters.

The implication is that either once the respondent moved closer to work she stopped telecommuting, or once she stopped telecommuting she moved closer to work. The latter explanation fits more closely with the temporal logic of the result (if the move came first there would be at least one quarter for which the respondent would be a *Current* telecommuter living closer to work, which would attenuate the differences among the three groups), but the former explanation is still possible for some cases. Further, if *ceasing* to telecommute is more likely a response to, rather than a cause of, moving *closer* to work, the same logic seems to support the inference that *beginning* to telecommute is more likely a response to, rather than a cause of, moving *farther* from work. That is, telecommuting appears more likely to be, on net, a benign travel reduction tool rather than a malignant instigator of sprawl. Although these conclusions are far from definite based on the evidence presented here, Ory and Mokhtarian (2004) explore which of the two directions of causality is more likely, by analyzing the temporal sequence of moves and telecommuting episodes, and by cross-tabulating self-reports of the importance of telecommuting to a move decision against the changes in commute length resulting from that move.

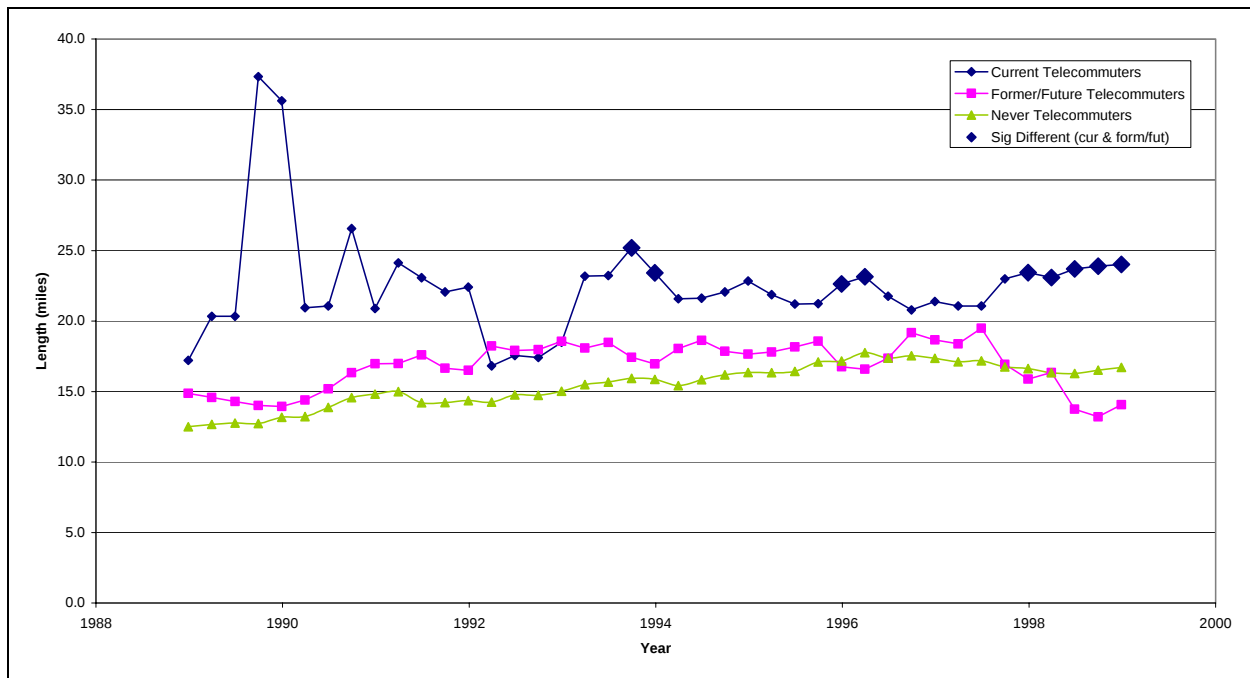


Figure 1: Quarterly Average One-way Commute Length

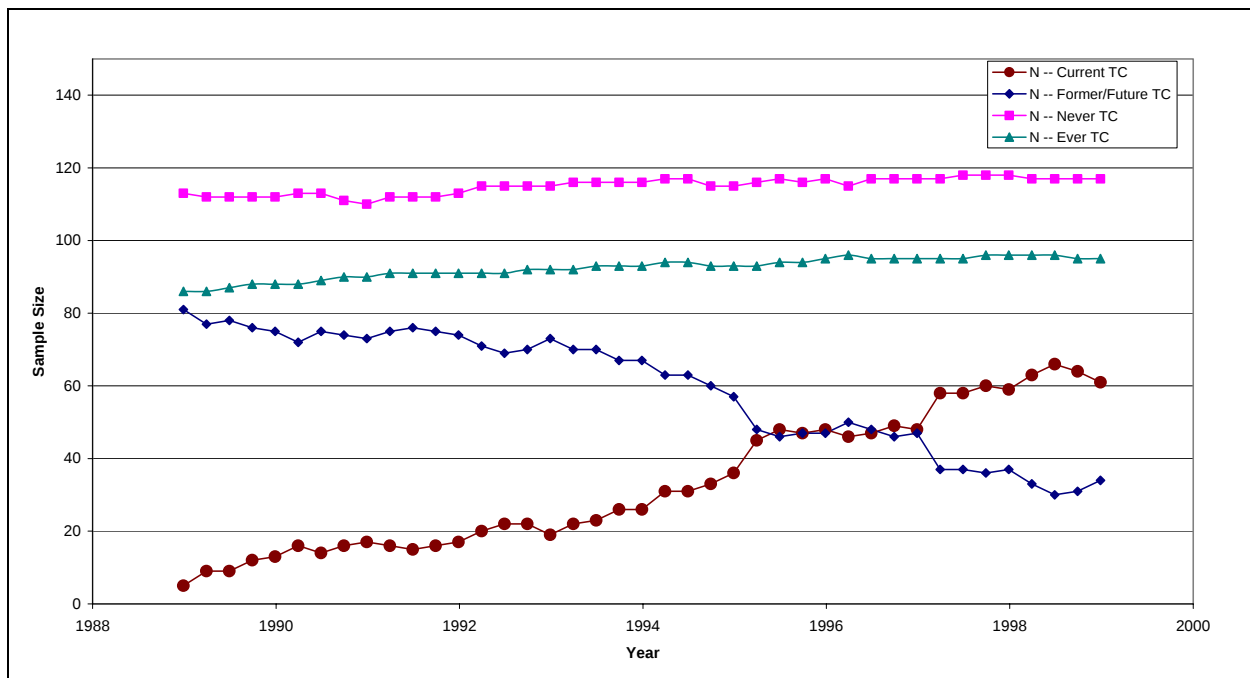


Figure 2: Sample Sizes for Telecommuter Market Segments through Time

The commute duration results are shown in Figure 3. This plot shows similar results, as expected, to the commute length plot. Again, Current telecommuters live farther from work (in terms of time), on average, than Former/Future telecommuters and Former/Future telecommuters live farther from work than Never telecommuters. Here, only the differences between the Current and Former/Future telecommuters during the last three time intervals are significant (as shown by the large diamond markers on the Current series).

The results in this section establish an important starting point: telecommuters do live farther from work than non-telecommuters. This finding is critical because the contention being examined is that telecommuting prompts workers to live farther from work and, in doing so, increase their commute travel over non-telecommuters'. For this point to warrant further investigation, the evidence should at least point to telecommuters, over a ten-year period, consistently living farther from work than non-telecommuters.

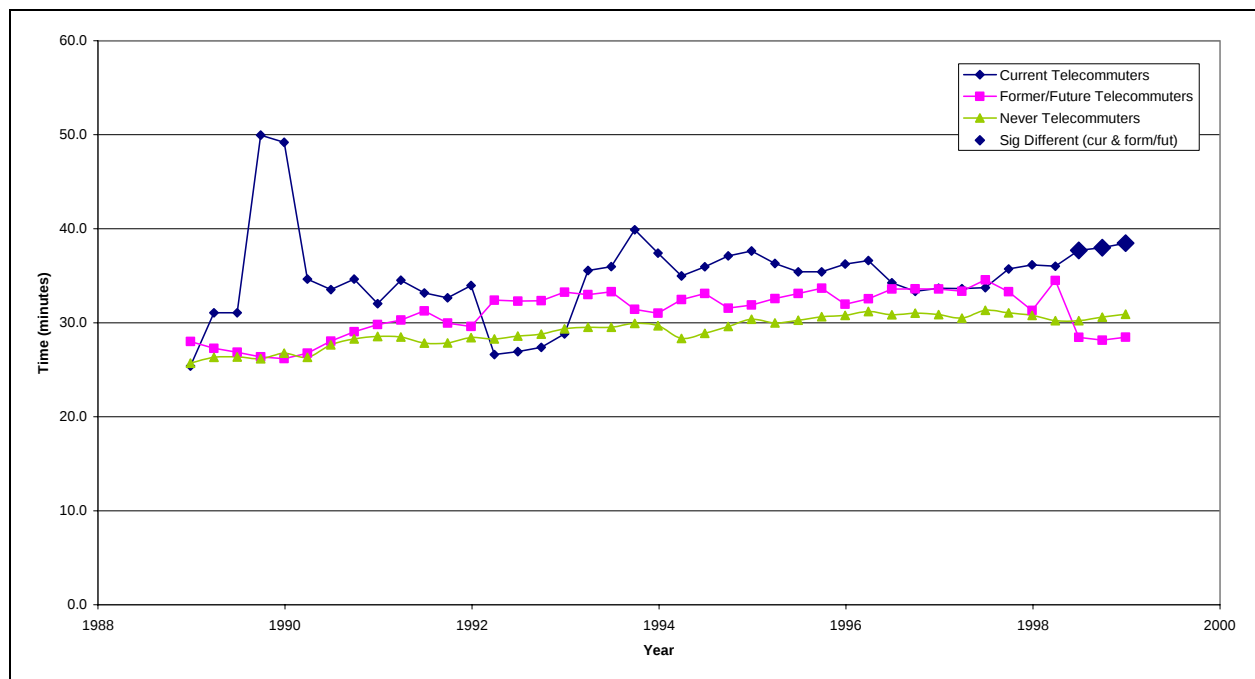


Figure 3: Quarterly Average One-way Commute Duration

5. Commute Speed

The results in Section 4 indicate that the differences in commute length between Current and Former/Future telecommuters are of greater magnitude than the differences in commute duration. The implication is that commute speeds differ by group, a speculation that is investigated in this section.

A comparison of average commute speeds between Current, Former/Future and Never telecommuters is presented in Figure 4. The individual average commute speed is computed from the self-reported commute length and duration measures captured by the survey instrument, and then averaged across individuals in each group, for each quarter. Compared to the plots of commute length and duration in Section 4, the plot of commute speed shows a more convincing difference between Current and Former/Future telecommuters; 20 of the 41 points are statistically different (shown by the larger markers on the Current telecommuter series). It is interesting that among one-way commute length, duration, and speed, the most telling difference between Current and Former/Future telecommuters is travel speed. Somehow, telecommuters are, rather consistently, traveling faster than their non-telecommuting counterparts, with the speeds of the Former/Future telecommuters generally higher than, but statistically indistinguishable from, those of the Never telecommuters.

These differences inspire numerous hypotheses, including: telecommuters may be living more on the urban fringe compared to non-telecommuters, allowing them to spend more time on less congested roadways; Current telecommuters may have more flexible time-of-day work schedules on days they travel to the office, allowing them to avoid peak-hour congestion; and, Current telecommuters may be more likely to commute by automobile than the control group.

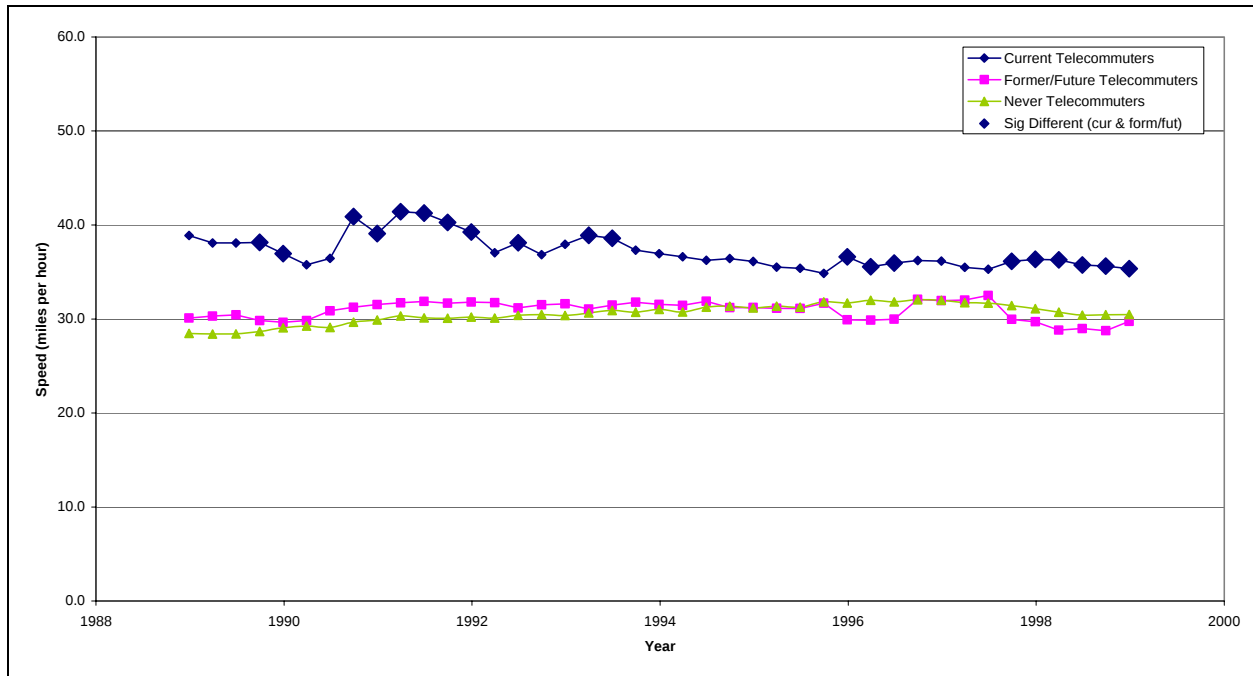


Figure 4: Quarterly Average Commute Speed

The first hypothesis is supported by the data: Table 1 shows that telecommuters in this sample are far more likely than Never telecommuters to live in the country side, medium-size city, or suburb, and less likely to live in a large city. Similarly, Table 1 supports the second hypothesis: telecommuters in this sample are less likely to work conventional work schedules than Never and Former telecommuters and are more likely to work a flextime or compressed schedule. Unfortunately, the data for city type and work schedule type is only available for the final quarter of data collection. Such a constraint is not in place for the third hypothesis: Current telecommuters travel more by automobile than Former/Future telecommuters. At the start of the ten-year study period and after each relocation, the survey instrument asked the respondents for their primary commute travel mode via an open-ended response question. As such, a total of 34 unique responses were received, ranging from detailed (e.g. drive alone-light rail) to vague (e.g. transit). These responses were converted into three simple modes – automobile, transit, non-motorized – using straightforward precedence rules, as follows: if the mode contains any transit component (e.g. train, auto-light rail, drive alone-BART), it is labeled as transit; next, if the mode contains any automobile component but no transit component (e.g. drive alone-walk, car, carpool-bicycle), it is labeled as automobile; finally, if the mode contains no automobile or transit component (e.g. walk, walk-bicycle), it is labeled non-motorized. Each respondent was assigned a simple commute travel mode for each quarter during the ten-year study period.

Figure 5 presents the automobile mode share for Current, Former/Future, and Never telecommuters.

Figure 5 indicates that toward the beginning and end of the study period, Current telecommuters were more likely to travel by automobile than Former/Future telecommuters. However, for at least half of the series the difference in share between the two groups is negligible, and the dominant trend is the difference in automobile share between Ever and Never telecommuters. These results suggest that the ability to travel by automobile is not the sole (and probably not the dominant) reason why Current telecommuters are able to travel at higher speeds than Non-telecommuters (Former/Future and Never).

A limitation of these results is the imprecise measurement of travel mode. The conversion from the 34 complex travel modes to the three simple travel modes has the potential to be misleading. For example, an individual traveling 30 miles in an automobile from the suburbs to the central business district and then hopping on a downtown circulator to move from a distant parking location to his office is considered, by our methodology, to be a transit traveler; a worker traveling 50 miles on a cross-town city bus will have a similar designation. The actual travel experiences of these individuals may be very different. However, to the extent these factors influence each market segment in the same way, they will not bias the results.

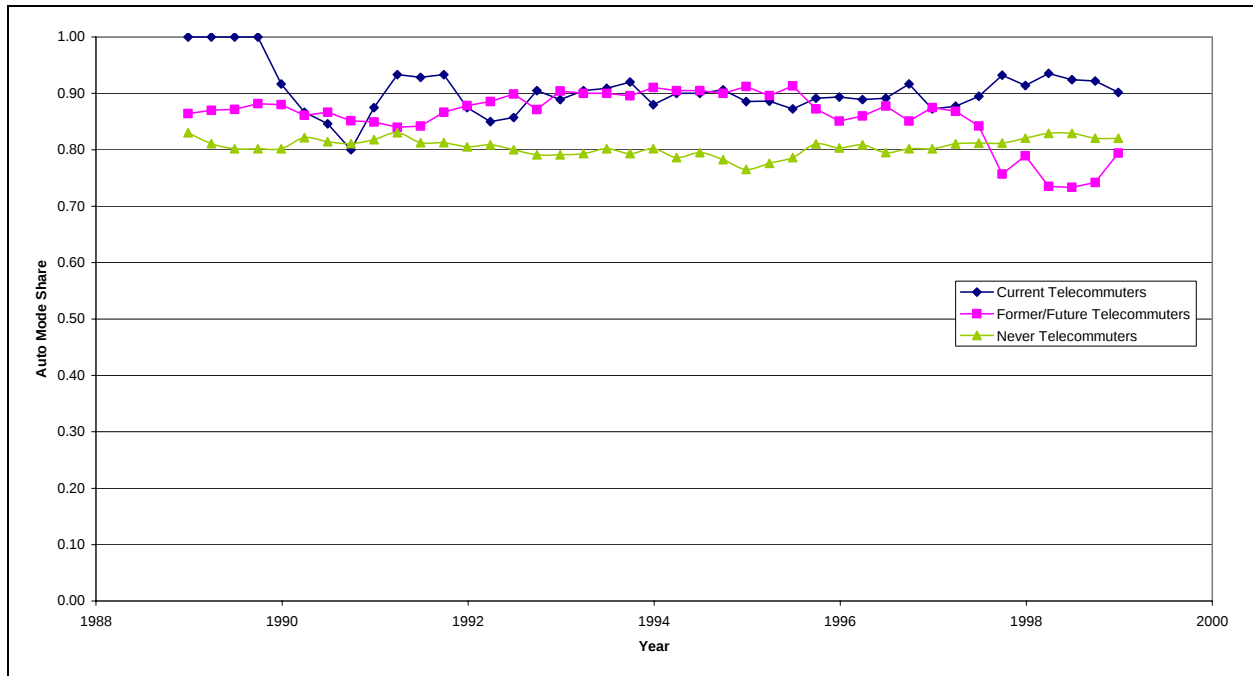


Figure 5: Auto Mode Share across Telecommuter Segments

6. Commute Person-Miles and -Minutes Traveled

As shown in Section 4, Current telecommuters tend to live farther from work in terms of time and distance, on average, than Former/Future telecommuters, with both groups tending to live farther than Never telecommuters. This suggests that, all else equal, Ever telecommuters would engage in more commute travel than Never telecommuters. However, there are several ways in which the longer one-way commutes of Ever telecommuters can be compensated for such that total commute amounts would be lower:

- By themselves, contemporaneously: Current telecommuters could telecommute often enough that their total commute travel is less than that of Never telecommuters.
- By others, contemporaneously: Not all Currents may telecommute often enough to make their overall commute travel lower, but their surplus travel could be more than outweighed by the savings of other Currents.
- By themselves and/or others, longitudinally: Greater commute amounts during non-telecommuting episodes (i.e. as Former/Futures) could be outweighed by commute reductions during telecommuting periods (i.e. as Currents), at least at the aggregate level

if not by each individual. Those reductions are a function not only of how frequently the person telecommutes, but also for how long a period.

In this section we assess whether any of these potential compensating mechanisms are supported by the data. Sections 6.1 and 6.2 investigate from the contemporaneous perspective, that is, comparing commute travel quarter by quarter. In Section 6.1, we calculate the average daily commute-miles and -minutes traveled by each of the three comparison groups, and find that Current telecommuters do, in fact, have less total commuting, on average, than either of the other two groups. This indicates that some combination of the first two mechanisms is in effect. To investigate the extent to which those results can be accounted for by the first mechanism alone, in Section 6.2 we determine the proportion of Current telecommuters who commute less than the medians for Former/Future and Never telecommuters. We find that 60.2% of Currents commute fewer miles than the median Never telecommuter of the corresponding quarter, and 65.2% of Currents commute fewer minutes than the median Never. Thus, clearly the second mechanism is in effect as well, so that the surplus commuting of above-average Current telecommuters is more than compensated for by the deficit in commuting of the below-average Currents.

The observation in Section 6.1, that Former/Future telecommuters commute even longer distances and times than Never telecommuters (because their one-way commutes are longer, and they are not telecommuting to compensate), raises the question of whether the surplus commuting generated during those non-telecommuting episodes (when they are Former/Futures) is outweighed by the commute reductions during their telecommuting episodes (when they are Currents). Thus, Section 6.3 turns to a longitudinal analysis of the data: we compare the per capita daily commute-miles and -minutes of Ever versus Never telecommuters, computed over the entire ten-year study period. We find that over the decade of interest, Evers do commute slightly more than Nevers on average. In particular, Evers commute 2.6% more distance (although 4.4% less time), in the aggregate, than Nevers during the ten-year study period. These results are discussed further in Section 6.3.

6.1 Quarter-by-Quarter Average Commute Person-Miles and -Minutes Traveled

6.1.1 Commute Distances and Times

In keeping with the organization of the preceding sections, Figure 6 shows the average two-way commute person-miles traveled (commute distance) for Current, Former/Future, and Never

telecommuters. Significant differences between Current and Former/Future telecommuters are shown in large diamond markers on the Current series. Figure 6 shows, rather consistently, that Current telecommuters travel less than (or, at worst, statistically similar amounts to) Former/Future telecommuters, who, in turn, travel more than Never telecommuters. In this view, telecommuting seems to be beneficial as telecommuters are traveling less, in the aggregate, than non-telecommuters. The fact that Former/Future telecommuters travel more than Never telecommuters is also expected: members of this market segment may be more attracted to telecommuting in the future, or may have telecommuted in the recent past, because of their high travel amounts.

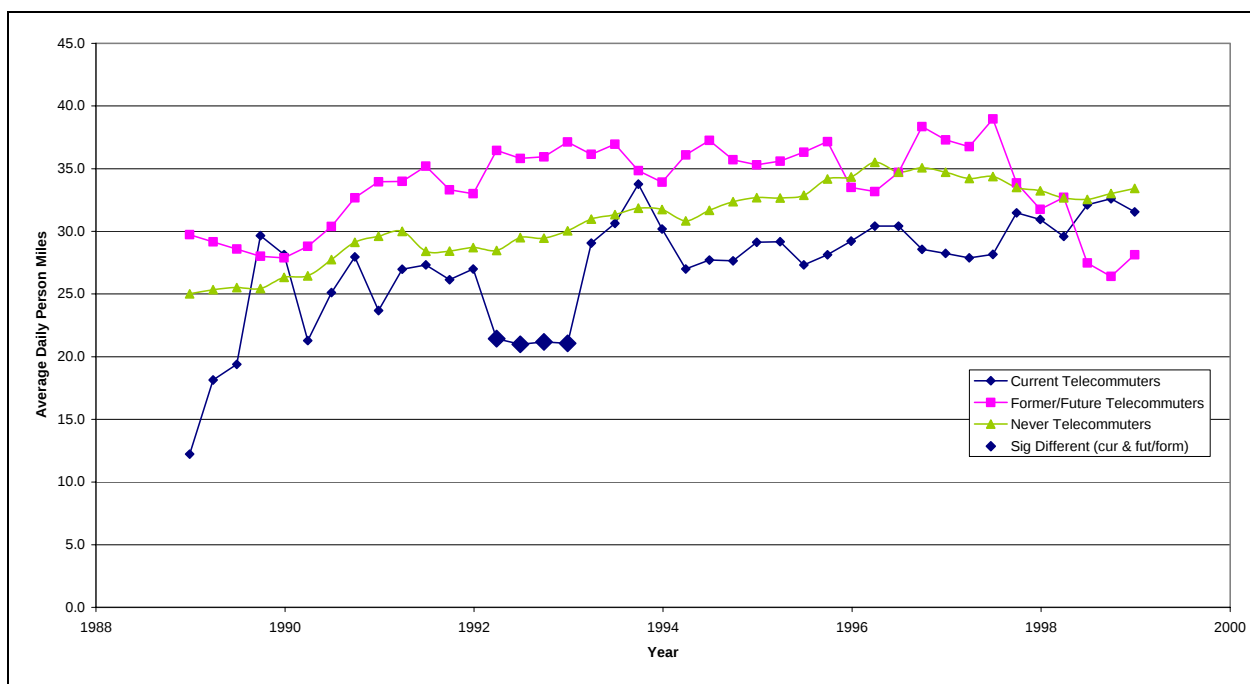


Figure 6: Average Daily Commute Two-way Person-miles Traveled

Figure 7 presents the same data for two-way commute person-minutes traveled (commute time). While the trends remain the same as in the person-miles plot, the differences are telling. Current telecommuters are traveling, on average, less than Former/Future telecommuters in all time periods, and significantly less for the majority (24 out of 41) of periods. However, the differences between Former/Future and Never telecommuters are much less than in the distance computations. This result may be due to the slightly higher speeds and higher automobile mode shares of Former/Future telecommuters compared to the Never market segment.

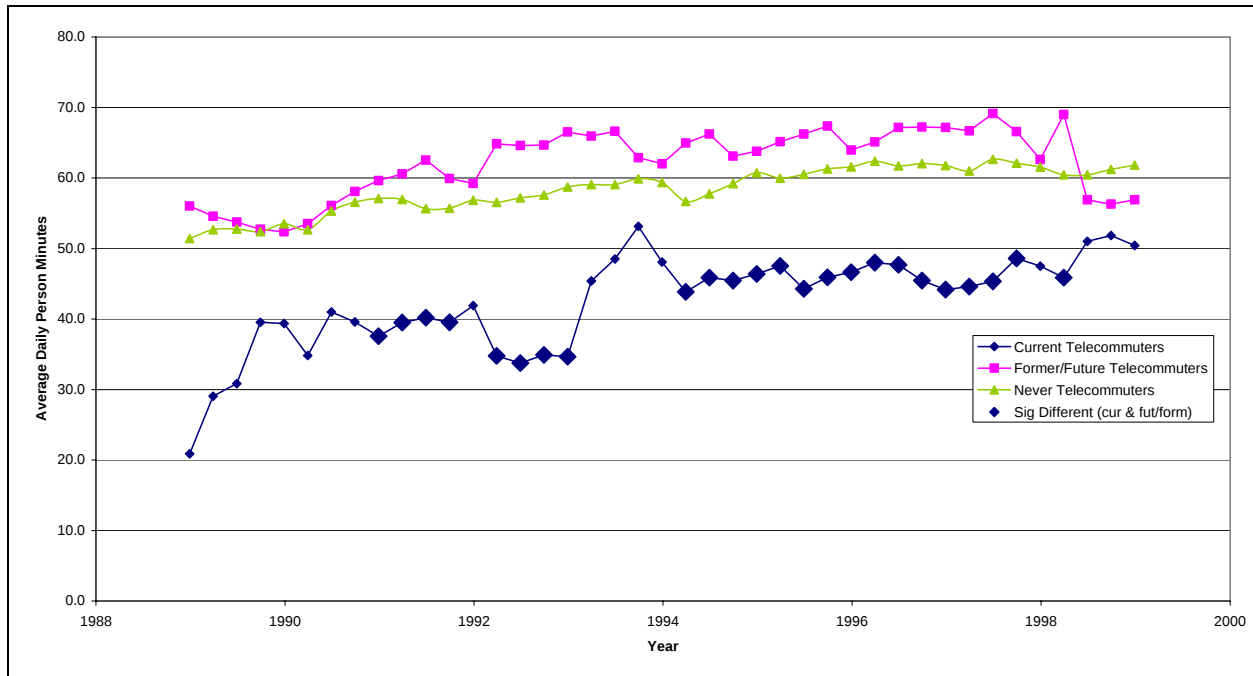


Figure 7: Average Daily Commute Two-way Person-minutes Traveled

When considering Figures 1, 3, 6 and 7 together, the idea of using telecommuting as a travel reduction policy seems appropriate. The fact that Ever telecommuters, during periods when they are *not* telecommuting (i.e. Former/Future telecommuters), commute more than the Nevers suggests (but does not definitively prove) that they have an innate tendency to live farther from work than average, whether due to a desire for a higher-amenity home, school, or workplace environment, or to other household constraints or preferences. Also, the fact that Ever telecommuters, during periods when they *are* telecommuting (i.e. Current telecommuters), commute *less* than when they are *not* (as well as less than Never telecommuters), indicates that telecommuting is an effective way to ameliorate the commute burden of this segment while allowing them to maintain their lifestyle preferences/needs. The larger differences in person-minutes traveled, compared to person-miles traveled, again suggest that travel speed is playing an important role in this relationship. As such, the impact of speed on travel amounts is examined further here.

6.1.2 What Saves More Time: Shorter Distances or Higher Speeds?

Figure 7 indicates that telecommuters are spending less time commuting than Non-telecommuters. A portion of this difference is a result of the shorter distances they are traveling (as shown in Figure 6) and a portion is a result of the higher speeds at which they are traveling (as

shown in Figure 4). To estimate the relative impact each of these two factors has on the end difference in travel times, the person-minutes traveled for Current telecommuters is recomputed by applying the quarterly average speed of Non-telecommuters to the commute distance of Current telecommuters (for simplicity of presentation, here we combine Former/Future and Never telecommuters to form Non-telecommuters). A plot of the resulting person-minutes traveled across time is presented in Figure 8.

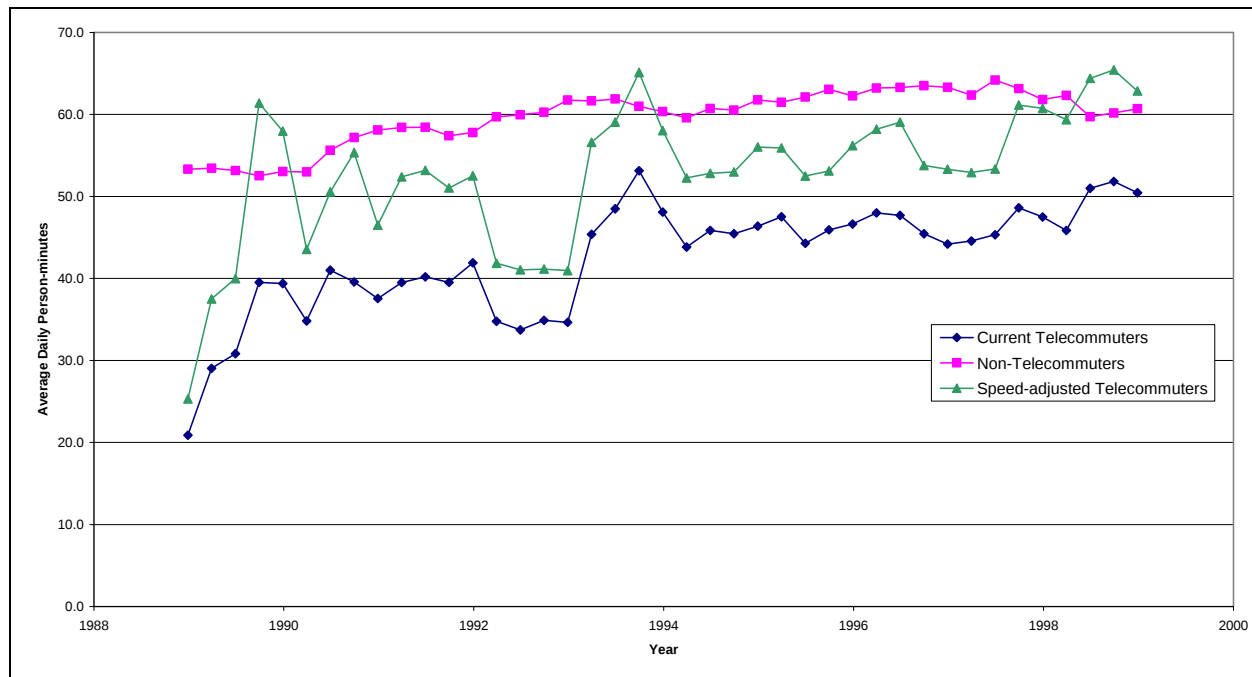


Figure 8: Average Daily Commute Two-way Person-minutes Traveled with Speed Adjustment

Using the results from Figure 8, the proportion of the difference between the Current telecommuter and Non-telecommuter series accounted for by the Speed-adjusted telecommuter series is computed. Thus, it is assumed that the Speed-adjusted series accounts for the difference in travel speed (which, at the aggregate level, it does exactly) so that the remaining difference between the Current and Non-telecommuter series can be said to be due to the difference in travel distances. The distribution of this so-called speed share ratio is shown in Figure 9; the average of this ratio is 0.701. The interpretation of this average value is that approximately 70.1 percent of the time savings enjoyed by telecommuters is due to their increased travel speeds; the remaining 29.9 percent of the time savings is due to their reduced travel distances. As such, the reasons behind the increases in travel speed (only hypothesized in Section 5) are extremely important to the travel-time-reducing benefits of telecommuting.

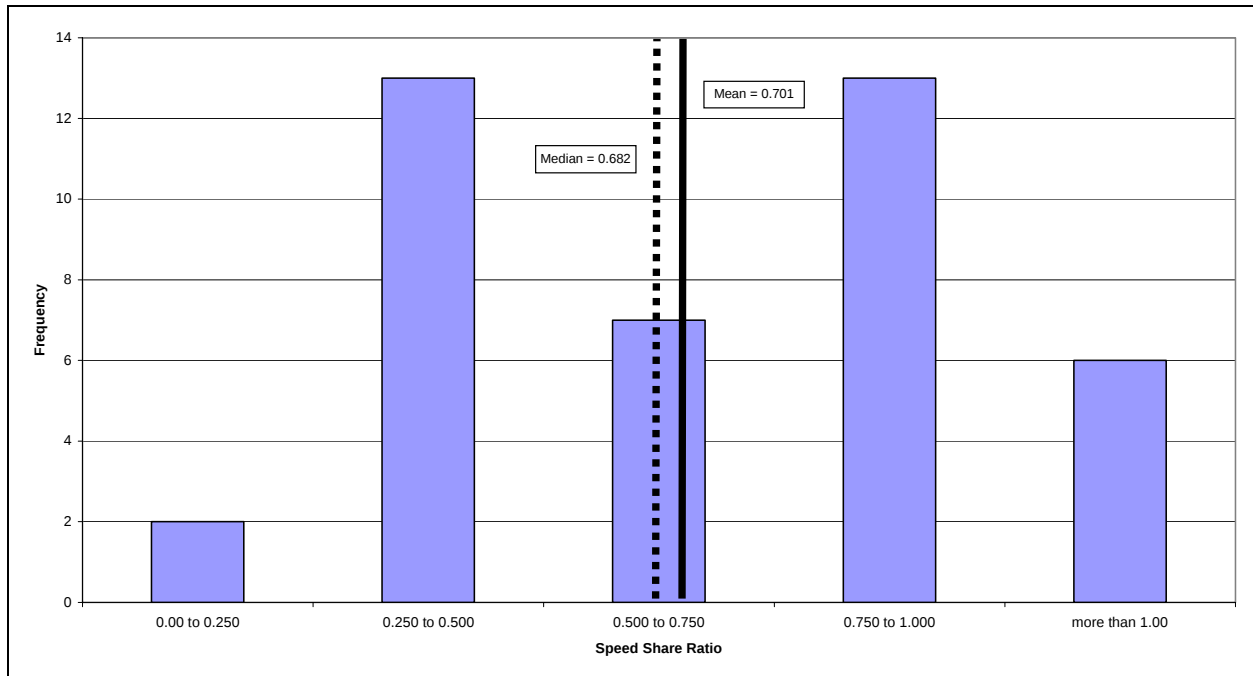


Figure 9: Speed Share Ratio Distribution for Telecommuters

6.2 Distribution of Individual Commute Amounts of Current Telecommuters

Figures 6 and 7 portray a positive picture of the impacts of telecommuting on total commute and time, but as mentioned earlier, a devil's advocate might wonder whether the average savings shown in those figures represent "typical" results or are skewed by large savings for a minority of individuals. Figures 10 and 11 address this question for distance and time, respectively. Figure 10 reproduces Figure 6, and adds two series representing, at each quarter, the percent of Current telecommuters whose commute distance falls below that quarter's median for Former/ Futures and Nevers, respectively. Figure 11 does the same for Figure 7 and commute time. From the data underlying the figures, it can be calculated that over the approximately 1,350 Current telecommuter person-quarters of the ten-year study period,

- Current telecommuters' daily commute-miles were lower than the Former/Future median (of the same quarter) in 62.4% of them, and lower than the Never median in 60.2% (see Figure 10);
- Current telecommuters' daily commute-minutes were lower than the Former/Future median in 67.7% of them, and lower than the Never median in 65.2% (see Figure 11).

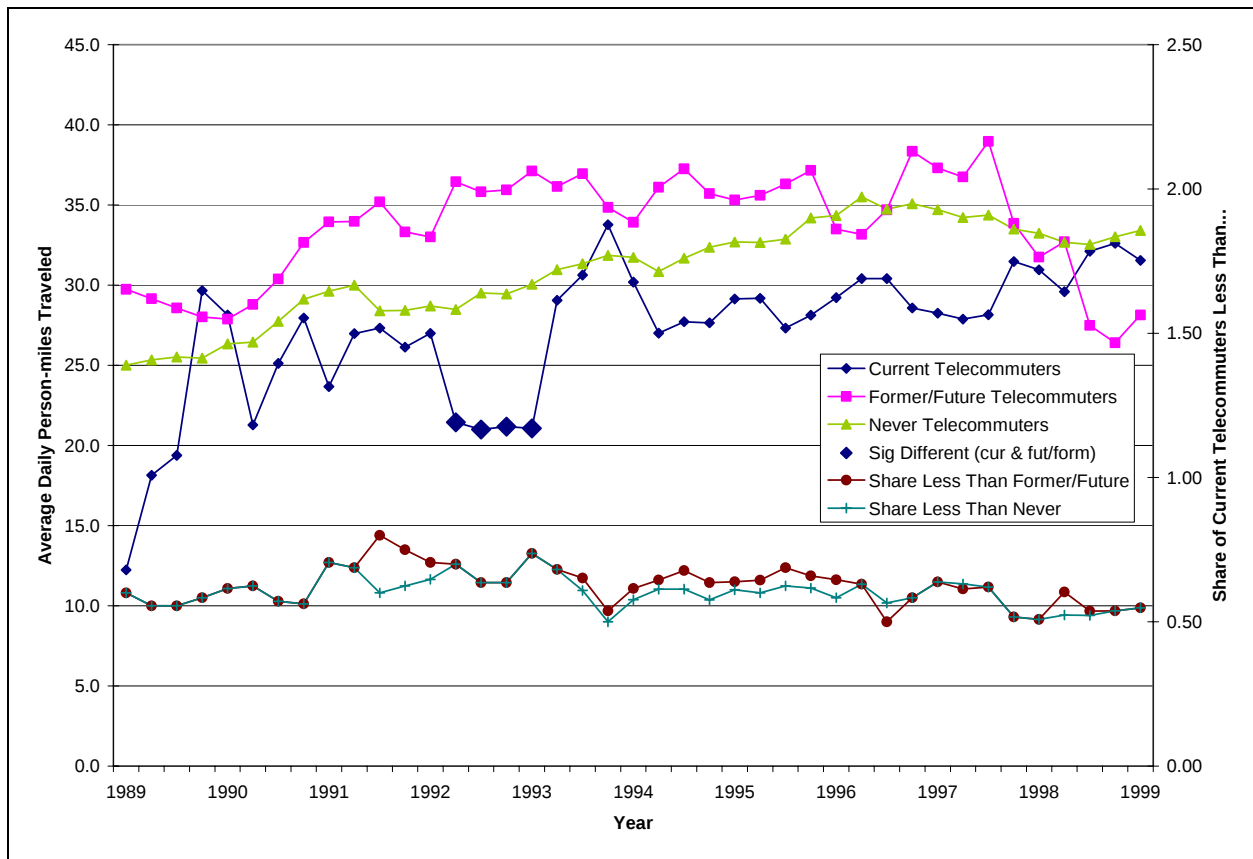


Figure 10: Average Daily Commute Two-way Person-miles Traveled with Shares of Current Telecommuters Less than the Median Former/Future and Never

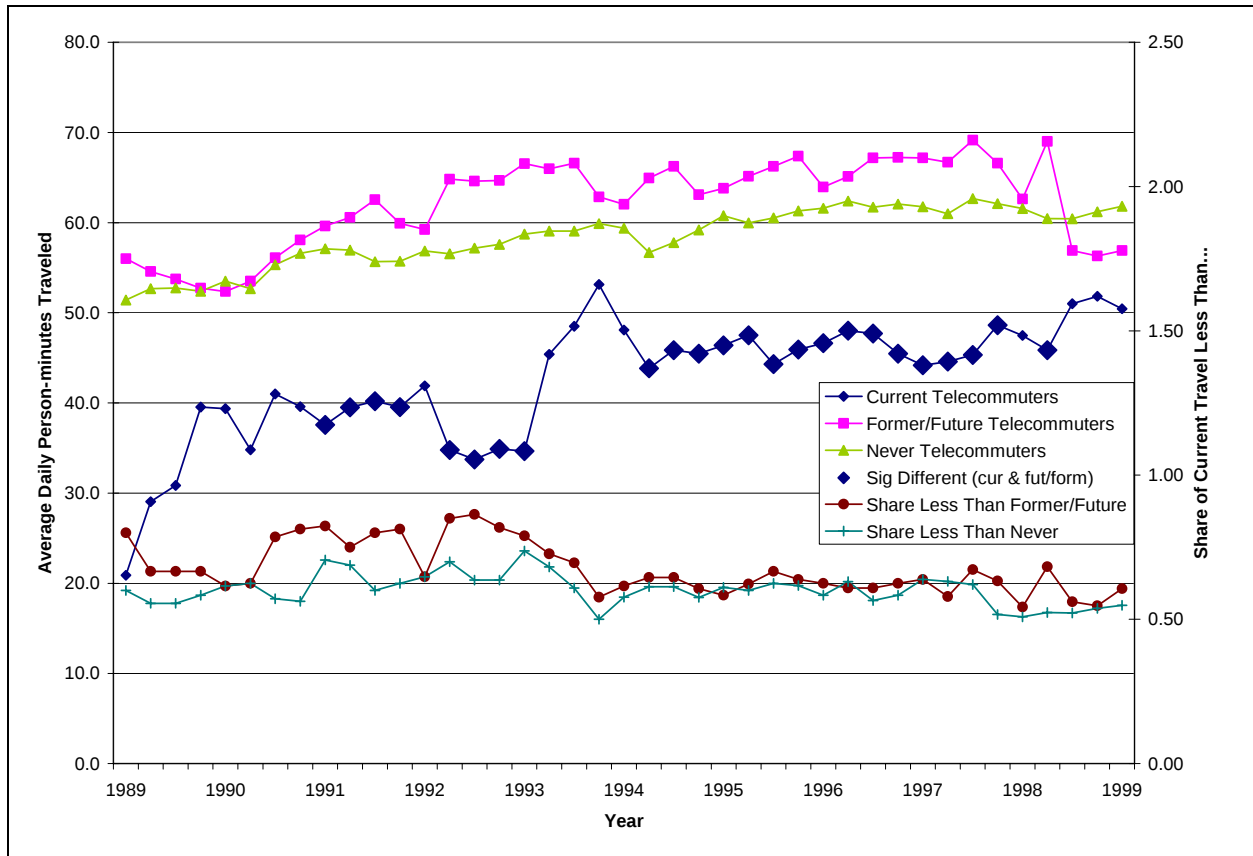


Figure 11: Average Daily Commute Two-way Person-minutes Traveled with Shares of Current Telecommuters Less than the Median Former/Future and Never

The conclusion is that the favorable result shown in the aggregate in Figures 6 and 7 is achieved at the individual level for a sizable majority (roughly two-thirds) of Current telecommuter person-quarters, with any surplus commuting of the remaining person-quarters being more than outweighed by the savings of that majority.

6.3 Longitudinal Analysis

For the longitudinal analysis we make two comparisons: one of Ever telecommuters against themselves, by comparing their commute behavior during telecommuting and non-telecommuting episodes, and one of Ever telecommuters against Never telecommuters, by comparing the overall commute behavior of each group across the ten-year period. Specifically, in the following two subsections we respectively answer two questions:

- How many individual Ever telecommuters actually commute less per day during their telecommuting episodes (when Currents) than during their non-telecommuting episodes (when Former/Futures)?
- Do Ever telecommuters commute less, per capita, over the entire ten-year study period than Never telecommuters?

The first question relates to how often Evers telecommute *frequently* enough during telecommuting episodes to compensate for their longer-than-average one-way commute lengths and times. The second question addresses whether, and how often, they telecommute *long* enough (as well as frequently enough) for their commute savings during those periods to outweigh their surplus commuting when they are not telecommuting.

6.3.1 Ever Telecommuters: When Telecommuting (Current) versus When Not Telecommuting (Former/Future)

To what extent do individual telecommuters reduce their commute travel during telecommuting episodes? To address this question, we consider only the travel of the 94 Ever telecommuters for whom complete commute distance and time information was available (along with complete telecommuting frequency information). The person-miles and -minutes traveled are then computed for each quarter in the study period. For each individual, the average of the daily quarterly averages of these quantities during quarters in which the individual telecommutes is compared to the same measure during quarters in which the individual does not telecommute. These computed ratios help answer the question: how often are individuals traveling more while telecommuting (due to moves farther from work or home or to changes in travel conditions) in comparison to individuals traveling less? The distributions of these ratios are shown in Figure 12.

The figure supports the positive view of telecommuting as a commute reduction policy for the majority of adopters, while giving some credence to the possibility of the negative view for a minority. On the positive side, the vast majority (approximately three-fourths) of respondents in the sample commute less (in terms of time and distance) while they are telecommuting than while they are not telecommuting (ratios less than 1.0 in Figure 12). Further, the average across all individuals results in an average ratio of less than one: telecommuters' daily commute person-miles traveled during telecommuting episodes averages 90% of that during non-

telecommuting episodes, and their person-minutes traveled during telecommuting episodes averages 77% of that during non-telecommuting episodes.

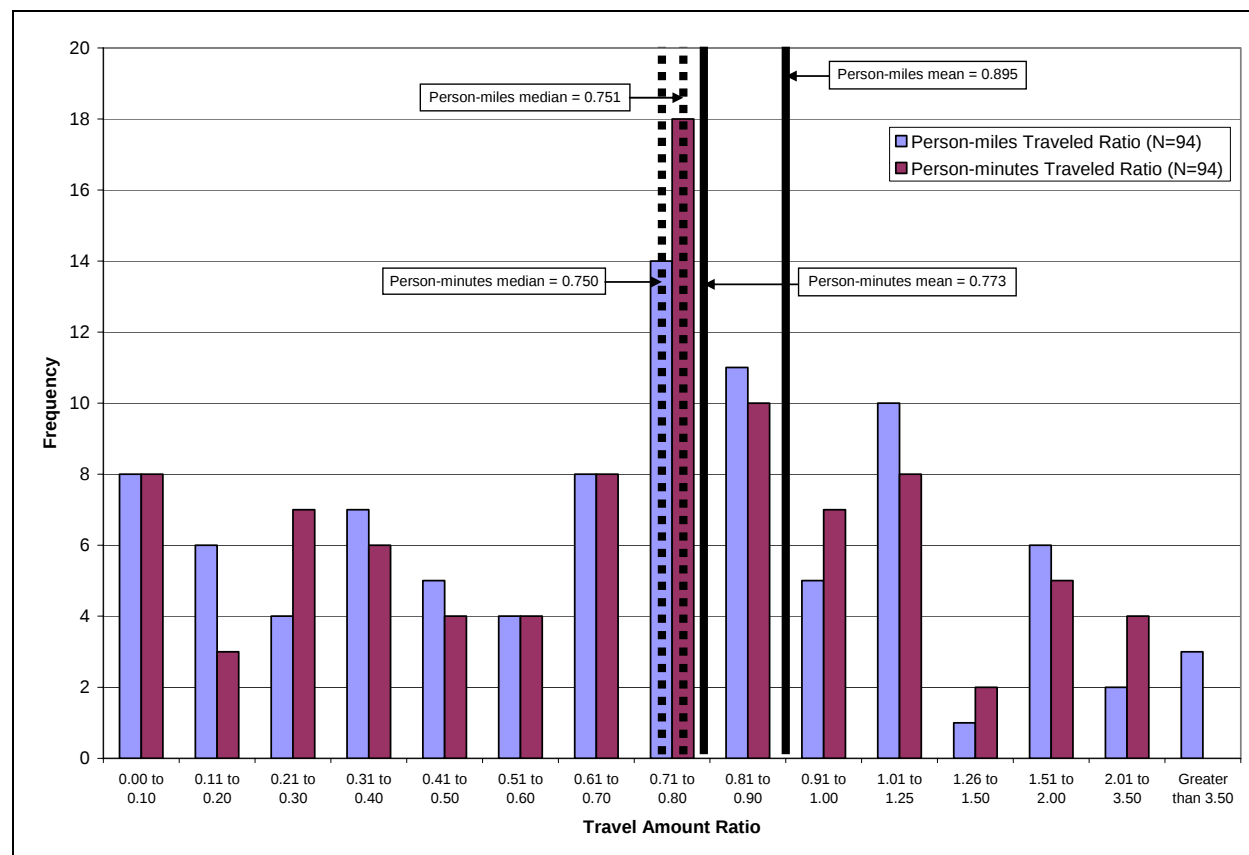


Figure 12: Distribution of the Ratio of Ever Telecommuters' Average Daily Commute Amounts between Telecommuting and Non-telecommuting Periods

To keep these ratios in perspective, it should be remembered that even during a so-called “telecommuting” period, Currents may be telecommuting as little as two days a month; certainly in general these workers commute more often than they telecommute. Even so, the average ratios may seem rather high when compared to Figures 6 and 7: there, Current telecommuters’ average daily person-miles traveled constitutes 81% of that of Former/Future telecommuters’ average, while their average daily commute time comprises 69% of Former/Futures’. The difference is that the numbers in Figures 6 and 7 compare the average commute amounts of Currents at each quarter with the average commute amounts of Former/Futures in the same quarter (where they are by definition a different group than the Currents, with sample sizes of each group varying from quarter to quarter), whereas the numbers presented in Figure 12 are

the averages of the paired comparisons of all Ever telecommuters with her/himself, during Current and Former/Future periods, respectively. The averages based on Figures 6 and 7 weight each quarter equally even though the subsample sizes differ for each quarter (and are quite small for Currents in the early quarters), whereas the averages in Figure 12 weight each individual and each telecommuting and non-telecommuting episode equally even though lengths of telecommuting and non-telecommuting episodes differ for each person. Thus, it is not surprising that the two sets of measures differ, but in the current context it is of interest to realize that the average commute savings *rate* of individual Current telecommuters, compared to the commutes of the same group when they are Former/Future telecommuters, is relatively modest (i.e., telecommuting results in only a 10% “discount” of miles and a 23% discount of minutes, on average using the mean, and a slightly more substantial discount of 25% of miles and minutes using the median).

In fact, on the negative side, approximately one-quarter of the sample commuted in greater amounts while telecommuting than while not. However, this result can be interpreted as a negative impact of telecommuting only to the extent that telecommuting *created* these increases in commute amounts by encouraging more distant residential or employment relocations. And even in the worst case that telecommuting is responsible for all of the additional travel by these respondents, telecommuting still has a positive *net* impact on commute amounts (with those who do save travel more than compensating for those who do not), as illustrated by the aggregate analysis shown in Figures 6 and 7 and by the average disaggregate ratios shown in Figure 12.

6.3.2 Ever vs. Never Telecommuters: Per Capita Commute Amounts over Ten-Year Study Period

Given that Ever telecommuters commute more, on average, than Nevers during their non-telecommuting periods, while commuting less than Nevers during their telecommuting episodes, it is of interest to ask: does their telecommuting compensate for their surplus commuting during their non-telecommuting periods, or are they still “commute villains” overall? That is, over a sustained period of time involving both telecommuting and non-telecommuting episodes – specifically, for the 10-year study period – do Ever telecommuters commute more, or less, overall, than Never telecommuters? This final question is addressed by Figures 13 and 15. Here, the sum and daily average of person-miles (Figure 13) and person-minutes (Figure 15) traveled are presented for each telecommuting market segment, as well as for the entire

sample. A comparison of the daily averages for each group is nearly equivalent (to the extent each person worked for the entire 10-year period) to comparing total commute amounts for each person (averaged within a group), while providing a more natural measure. As shown in Figure 13, the average commute distance for the entire sample is approximately 31.4 miles. Current telecommuters reduce this amount to 28.6 miles and those not currently telecommuting increase the amount to 31.9 miles. Those who Never telecommute during the ten-year period commute an average of 31.0 miles per day and those who do telecommute at some point, travel slightly more at 31.8 miles. The higher average in the Ever telecommuter segment is a result of the 33.6 mile average of Former/Future telecommuters.

Thus, because Ever telecommuters commute so much more than average during their non-telecommuting episodes, their telecommuting is not frequent and/or long enough to entirely negate those longer commutes and they end up commuting slightly (2.6%, comparing 31.0 to 31.8) longer distances, on net, than Never telecommuters during a 10-year period comprising both telecommuting and non-telecommuting episodes. The distributions of the commute distances for the entire ten-year period for Ever and Never telecommuters are shown in Figure 14 (the sample size in this figure is in units of persons). Interestingly, the *median* number of daily person-miles commuted by Evers is less than that of Nevers. And though not explicitly shown in the figure, only 38.1% of Evers' average commute distances are greater than the overall average of Never telecommuters, compared to 42.1% of Nevers exceeding their own average (however, the number of miles by which above-average Evers exceed the average is presumably slightly higher than the miles by which above-average Nevers do). Thus, the behavior of the Evers is not in fact very different from that of the Nevers. Further, even with their longer overall average, unless telecommuting can be blamed for those longer commutes, the Evers would be commuting even *more* if telecommuting had not been available to compensate for most (92%, comparing the 2.6 mi./day surplus commute distance traveled by Former/Futures over the Nevers, to the 2.4 mi./day deficit of the Currents over the Nevers) of the higher-than-average commuting.

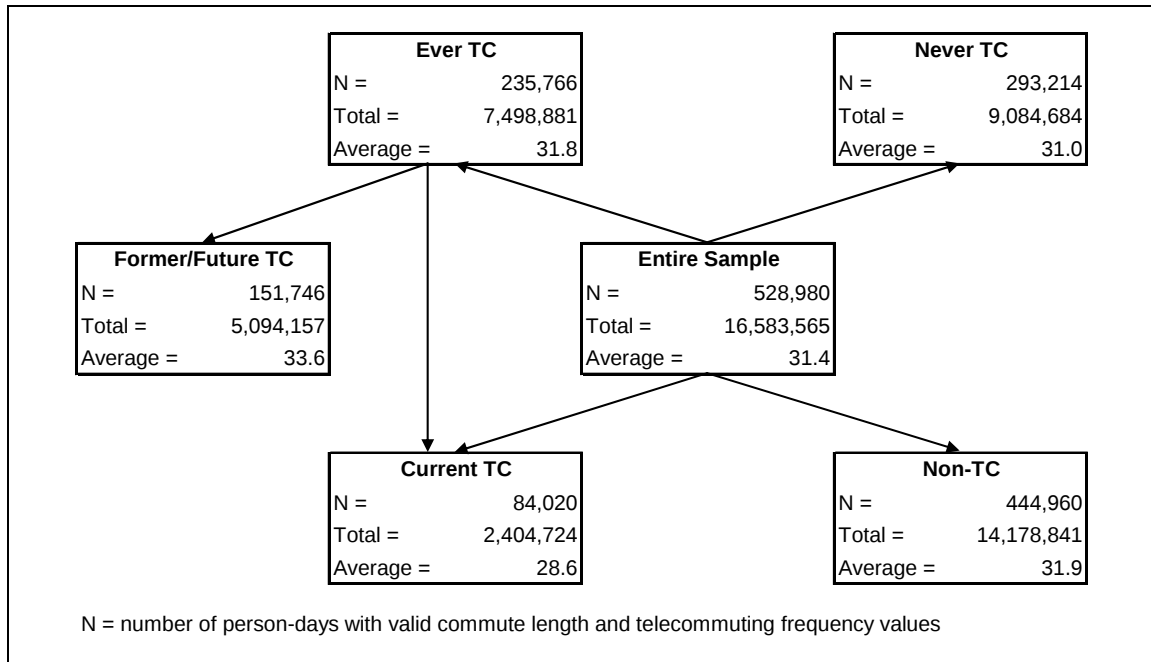


Figure 13: Person-miles Traveled by Telecommuter Market Segment

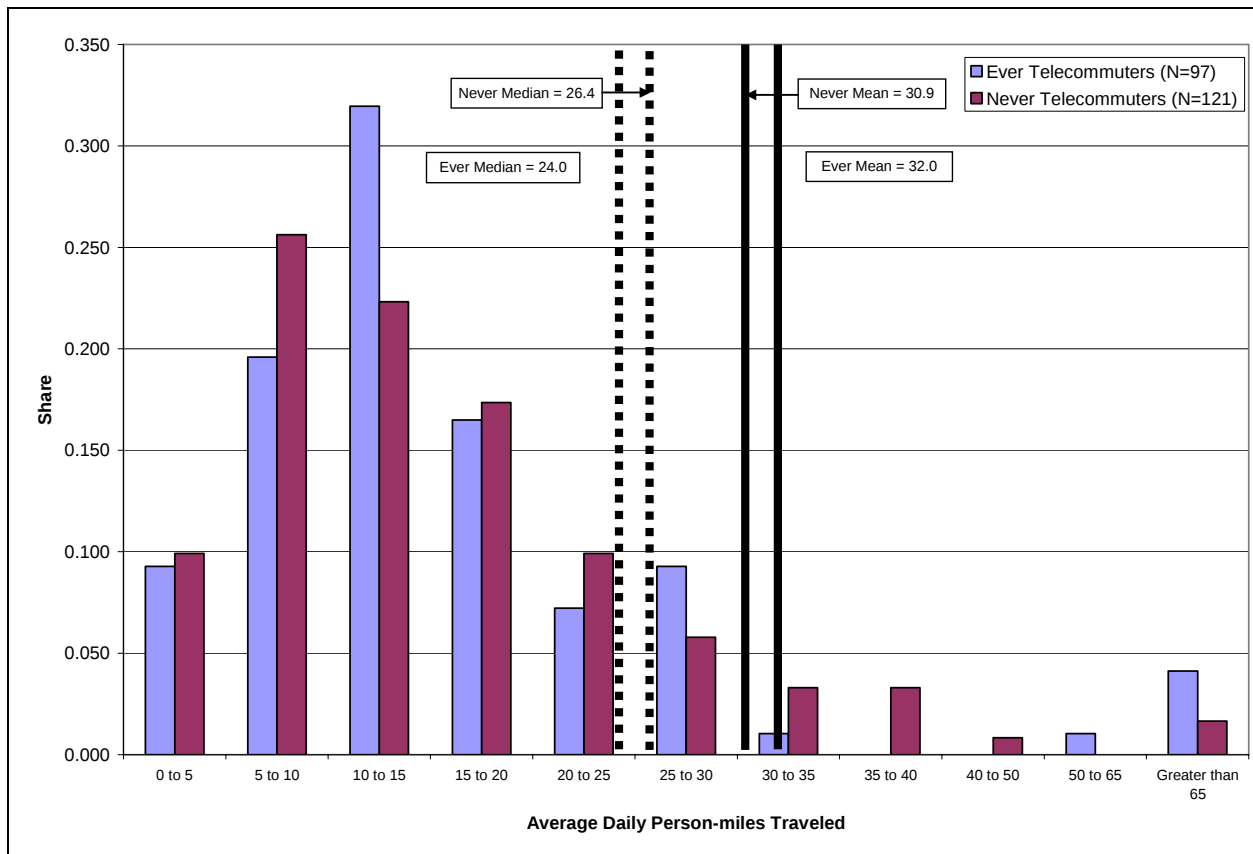


Figure 14: Distribution of Average Daily Person-miles Traveled over Ten-year Study Period

Similar results hold for the person-minutes traveled segmented averages shown in Figure 15, with the key difference that, in terms of time, the shorter distances and higher speeds of Current telecommuters do more than compensate for the longer-duration commutes of Former/Future telecommuters, with the net result that Ever telecommuters commute for 4.4% shorter durations, on average, than Never telecommuters. The distributions of the Ever and Never averages are shown in Figure 16; 36.1% of Ever telecommuters' average commute times are greater than the overall Never average, compared to 44.6% of Nevers exceeding their average. Once again, the median for the Never group is larger than the median of the Evers.

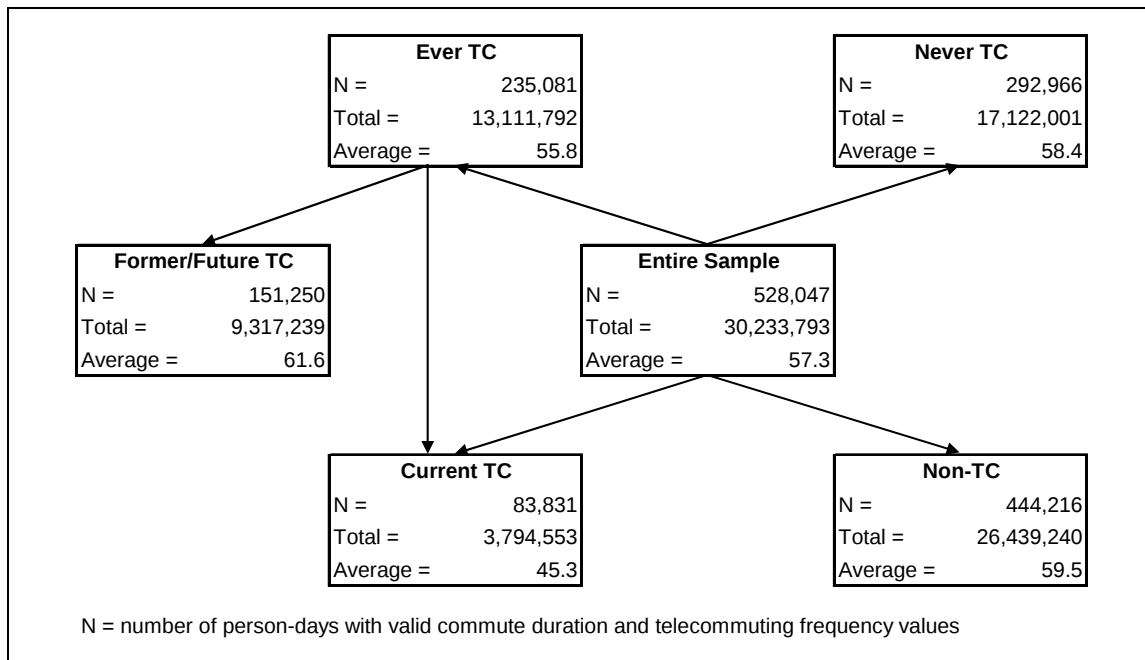


Figure 15: Person-minutes Traveled by Telecommuter Market Segment

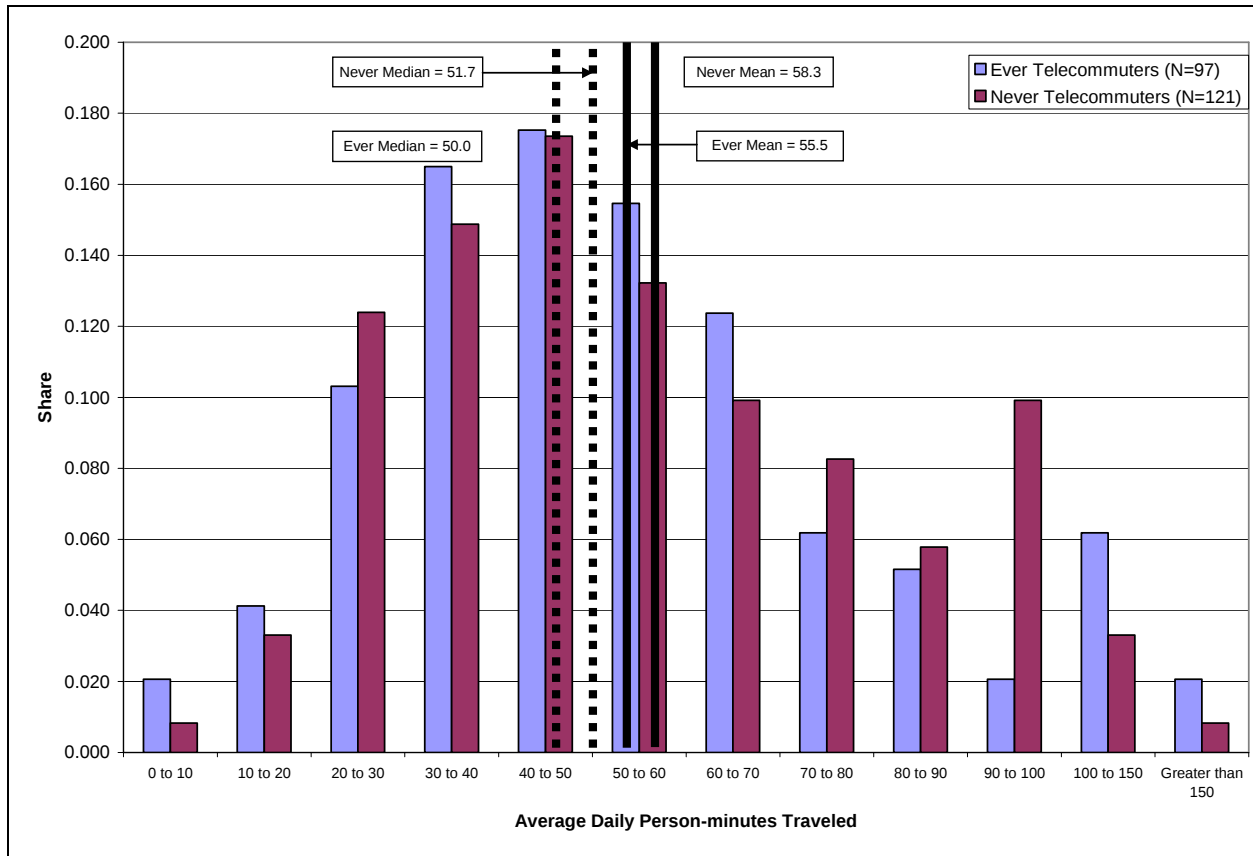


Figure 16: Distribution of Average Daily Person-minutes Traveled over Ten-year Study Period

The results shown in Figures 13 and 15 can be interpreted in two very different ways. On one hand, the slightly higher travel distances and lower travel times of Ever telecommuters compared to Never telecommuters suggests that, at the aggregate level, the availability of telecommuting as an option resulted in small increases in overall commute distance and decreases in commute time. This would suggest that telecommuting is having a relatively minor impact on travel amounts. On the other hand, however, to the extent that those in the Former/Future telecommuting market segment travel more due to innate desires or constraints, and those factors would be present with or without telecommuting options, telecommuting can be viewed as a very successful commute reduction policy in that it is adopted by a high-travel population, and substantially reduces their travel (by 15%, comparing the 33.6 mi./day average of Former/Futures to the 28.6 mi./day average of the Currents, not even considering the fact that Currents live even farther from work than do the Former/ Futures, as shown in Figure 1). To properly determine which interpretation is correct, the question of causality (are telecommuters relocating to distant locations? Or, are those living in distant locations deciding to telecommute?) needs to be addressed, as is done in Ory and Mokhtarian (2004).

7. Summary and Conclusions

In this study we investigate ten-year retrospective data on the telecommuting engagement and commute amounts of a sample of 218 employees of six California state agencies that have operated telecommuting programs since 1998. The current study focuses on the relationships between telecommuting and commute distances, times and speeds. This paper complements previous studies of the same data that focused on travel distances and the causal relationships between telecommuting engagement and residential/job relocations.

This paper used former and future telecommuters as a comparison group to which currently telecommuting workers are compared (with classification being determined on quarter-by-quarter basis). As such, the Former/Future group is assumed to represent the counterfactual conditions for telecommuters if they had not been telecommuting, and both groups are also compared to respondents who Never telecommuted during the study period. Initially the following questions were addressed:

- Do telecommuters live farther from work than non-telecommuters?
- If so, do they telecommute frequently enough to commute less, on average, than non-telecommuters?
- What relative roles do distance and speed play in determining the reductions in commute travel time offered by telecommuting?

Compared to Never telecommuters, Ever telecommuters have longer one-way commutes (in terms of time and distance) on average, but commute less frequently during telecommuting episodes. The end result is that Current telecommuters commute less, in terms of average daily person-miles (15% less) and -minutes (26% less), than Former/Future telecommuters (despite the fact that Currents live somewhat farther from work than Former/Futures at the outset). Current telecommuters also travel at higher speeds than their non-telecommuting counterparts. The difference in travel speeds, only partially explained by differences in commute travel mode, may be due in part to telecommuters having the ability to travel during off-peak times (on days they do travel to work) or a result of telecommuters living on the urban fringe, where segments of their journey to work may be less congested. It is estimated that approximately 70 percent of the commute time savings telecommuting provides is a result of these higher speeds, with the

remainder due to the shorter total distance traveled. These results led us to further investigate the individual and collective behavior of telecommuters, asking:

- To what extent do individual telecommuters reduce their commute during telecommuting episodes?
- Given that Former/Futures commute even more than Nevers, does the savings they accrue during telecommuting episodes (i.e. when they are Currents) outweigh the surplus commuting they generate during non-telecommuting episodes? That is, over a sustained period of time involving both telecommuting and non-telecommuting episodes, do those who at any point telecommute commute more, or less, overall, than those who never telecommute?

About three-quarters of the Ever telecommuters commute less (in terms of time and distance) while they are telecommuting than while they are not telecommuting. On average, while telecommuting, they commuted for only 90% of the distance (75% using the median rather than the mean) and 77% of the time (75% using the median) they traveled while not telecommuting.

However, when examining the aggregate commuting amounts over the entire ten-year study period, those who telecommuted at some point in the ten-year period averaged slightly (2.6%) more person-miles traveled (although 4.4% fewer minutes) than those who did not engage in telecommuting. This result could be interpreted as indicating either that telecommuting, in the aggregate, provides no travel savings and actually increases travel, or that telecommuting is effective in that it attracts those who would otherwise commute even more, and substantially reduces their travel. The choice of interpretation is dependent on whether or not one believes that those who initially commute longer distances are then attracted to telecommuting as a commute reduction mechanism, or, conversely, that those initially with the ability to telecommute then move to more distant locations and, in doing so, increase their commute amounts. This issue of causality is the focus of another paper (Mokhtarian and Ory, 2004), which finds that the more benign interpretation of the role of telecommuting (that is, as an effect rather than a cause of longer one-way commutes) is the stronger one. Thus, it appears reasonable to develop and maintain policies to increase telecommuting, from the perspectives both of travel reduction and of time savings to promote better work/life balance. Since telecommuting is arguably a self-rewarding choice, these policies should perhaps focus more on

removing barriers to increased adoption (which could be legal/regulatory, technological, or institutional) than on providing incentives for individual workers to adopt it.

Due to the relatively small sample sizes and isolated sample used in this study, more research is needed. Ideally, comparable groups of telecommuters and non-telecommuters should be tracked over a long period of time to more directly measure the impact of telecommuting on residential/job relocations and commuting over time. Having a full range of socio-demographic and attitudinal data through time would also be extremely useful for analyzing the influence of those factors on telecommuting engagement and frequency. The findings in this paper demonstrate the importance of determining the direction of causality in the relationship between telecommuting and residential relocation. Further, the significantly faster commute travel speeds of telecommuters warrants more investigation into possible reasons for this result.

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