An Empirical Analysis of Causality in the Relationship between Telecommuting and Residential and Job Relocation

David T. Ory
Department of Civil and Environmental Engineering
and
Institute of Transportation Studies
University of California, Davis
Davis, CA 95616
voice: (415) 378-9102
fax: (530) 752-6572
e-mail: dtory@ucdavis.edu

and

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

February 2005

This research is funded by the National Science Foundation Integrative Graduate Education and Research Traineeships (IGERT) program and the University of California Transportation Center (UCTC)

Table of Contents

List of Tables

Acknowledgements

The initial survey design, data collection, and analysis for this project were funded by BMW AG and performed by Dr. Carsten Gertz and Vikram Thairani together with the second author of this report. Funding from the University of California Transportation Center permitted further analysis of the data by Gustavo Collantes. This previous work was invaluable in preparing the data for the analysis presented here, which is funded by a National Science Foundation Integrative Graduate Education and Research Traineeships (IGERT) fellowship. The assistance of Colby Brown and valuable comments of Ilan Salomon are gratefully acknowledged. We also acknowledge with appreciation the assistance of the State of California staff who facilitated the data collection effort, including David Fleming, Department of Personnel Administration; Nan Powers, California Energy Commission; Sue Teranishi, Franchise Tax Board; Elaine Scanlon, Department of Motor Vehicles; Dorothy Carter, California Youth Authority; and Tom Benson, Department of Social Services.

Executive Summary

Researchers have questioned whether the ability to telecommute is encouraging workers to relocate to more desirable residences farther from work, and in doing so, exacerbate sprawl and increase their net vehicle-miles traveled. The research presented here directly asks, is telecommuting a “friend or foe” of travel-reducing policies? Given that telecommuters tend to have longer commutes than non-telecommuters, is the ability to telecommute prompting workers to move farther away from work? Or, does the ability to telecommute allow those who for other reasons have already chosen, or would in any case choose, to live in more distant locations to commute less frequently? These questions are addressed using data collected from more than 200 State of California workers, including current, former, and non-telecommuters. The survey inquired retrospectively about their residential and job relocations, as well as their telecommuting engagements, over a ten-year period.

The results indicate that, as expected, residential and job moves that are temporally associated with telecommuting episodes tend to increase commute time and length compared to other moves – though the evidence is not statistically significant. Analyzing the temporal order of telecommuting engagement and residential relocation, the data show that those who are telecommuting and then move actually tend to relocate *closer* to their workplace, whereas those who begin telecommuting following a residential relocation tended to have moved much farther from their workplace. For job relocations, the results differed slightly. Here, both key casual groups (those who are inferred to have their relocation caused by telecommuting and those who are inferred to have their telecommuting engagement caused by relocation) relocate, on average, to jobs farther from home. Analysis of the stated importance of telecommuting to specific residential relocations did not show a convincing effect toward more distant moves. Linear regression models of the change in one-way commute length following a residential relocation confirm that the beginning of a telecommuting engagement following the move is associated with increases in commute length, whereas engagement before the move is not. Thus, the evidence more strongly supports the positive view of telecommuting, that it is ameliorating the negative transportation impacts of moves that occur for other reasons.

1. Introduction

Telecommuting has found a niche in U.S. transportation policy. In response to a number of convincing empirical studies (see, e.g., Hamer, *et al.,* 1991; Mokhtarian, *et al.*, 1995) that have found net reductions in the vehicle-miles traveled by telecommuters (on days they telecommute), policy makers at the state and national level have begun to incorporate telecommuting alternatives into law. United States Public Law 106-346 (Sec. 359, 2001), for example, states, "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."

The problem with the empirical evidence to date is that it tracks travel behavior over a very short period of time after the adoption of telecommuting – typically one to two years. The long-term impacts of telecommuting on travel, specifically commute travel, are not fully known. Certainly the evidence so far indicates telecommuting may reduce overall travel, but some researchers (see, e.g. Janelle, 1986 for an early source of this idea) have suggested that the ability to telecommute could, over time, prompt individuals to move farther away from their jobs to cheaper or higher-amenity residential locations. Such moves would require longer, though less frequent, commutes that may lead to a net increase in vehicle-miles traveled (VMT). To the extent such behavior occurs, telecommuting alternatives could accelerate urban sprawl, and may not serve their intended role of reducing travel. Suspicion of telecommuting deepens with the observation of several studies (see e.g., Mokhtarian, et al., 1995; Gareis, 2003; Shaw, 2004) that telecommuters tend to have significantly longer commutes than non-telecommuters.

On the other hand, the latter observation is not conclusive because the causal relationship could be in the opposite direction: people who have already moved far from work would naturally be more motivated to adopt telecommuting after the fact, as a solution to, rather than a cause of, their longer commute.

Thus, we ask: is telecommuting a friend or foe of travel reduction policies? Is the ability to telecommute prompting workers to move farther away from work and, hence, perhaps to increase their overall commute distance? Or, does the ability to telecommute allow those, who for other reasons have already chosen (or would in any case choose) to live in more distant locations, to commute less frequently and, hence, to reduce their total commute amount from what it would have been without telecommuting, even if it is still more than it was before the move?

It is important to keep in mind that telecommuters would not move farther from work just *because* they are able to telecommute. Rather, in the "foe" scenario, telecommuting simply makes possible a move that is desired for other reasons – to accommodate household needs, to obtain a larger and/or cheaper home, to be near scenic locations or other amenities, and so on. Thus, in this scenario, telecommuting can be viewed as a facilitator, not an actual driver, of such moves. Nevertheless, to the extent telecommuting is responsible for releasing a constraint that was preventing further decentralization (and to the extent such decentralization is considered socially undesirable), telecommuting is arguably as culpable as if it were a driver in its own right. In reality, of course, it could be rather difficult to disentangle the relative roles of drivers and facilitators, to determine the extent to which one factor could be singled out as being responsible for the move, as opposed to a number of factors acting in concert, with indivisible impact.

Several studies have examined the long-term impacts of telecommuting on residential location, and hence urban form, using economic theory. Higano and Orishimo (1990), Lund and Mokhtarian (1994), Kim (1997), and Safirova (2001) assumed a monocentric city; Stough and Paelinck (1996) and Shen (2000) relax the monocentric assumption in different ways. Each of these studies found, not surprisingly, that telecommuting can increase the rate of decentralization of a city. However, none of these theoretical models has been empirically verified. Unfortunately, the ideal data set, which would track telecommuters and comparable non-telecommuters over a substantial period of time (e.g. 10 years), does not exist. As a result, it remains difficult to confirm or refute the alternative conjectures as to the causal relationship between telecommuting and residential (or job) relocation.

In lieu of the ideal data set described above, the present study analyzes a single cross-sectional survey of current, former, and non-telecommuters – inquiring retrospectively about their residential and job relocations, as well as their telecommuting engagement patterns, over a ten-year period (from the fall of 1988 to the fall of 1998). Though such data are obviously subject to recall error, the changing of residence or job location is probably an important enough life event to be recalled with the desired accuracy – the unit of analysis being a quarter-year or 3-month period (for a more detailed discussion of the use of retrospective surveys for collecting residential relocation data, see Hollingworth and Miller, 1996). Telecommuting engagement is probably a less significant life event, though perhaps memorable enough that respondents seemed to have little trouble answering the questions in the survey (relatively few missing or unclear data). To our knowledge, this study (including other analyses of the same data) constitutes the first attempt to empirically examine relationships among telecommuting, residential location, job location, and total commute travel over a ten-year period.

A previous analysis of these data (Mokhtarian, *et al.*, forthcoming) confirmed that in this sample, too, telecommuters lived farther from work than non-telecommuters. However, it also found that the telecommuters telecommuted often enough to more than compensate for this: the total per capita commute distance traveled by telecommuters was smaller than for non-telecommuters. A later extension of that analysis (Ory and Mokhtarian, 2004) found that telecommuters also commuted for shorter durations than non-telecommuters, with the majority of that time savings due to faster travel speeds. Those studies, however, did not address whether the longer one-way commute length of telecommuters was a cause, or an effect, of their telecommuting. In contrast, the focus of the present analysis will be on attempting to ascertain causality.

Attributing causality in the relationship between residential/job relocation and telecommuting is difficult because individuals move closer to and farther from work all the time and take jobs that are closer to and farther from their homes all the time, for a variety of reasons that most often have nothing to do with telecommuting. The behavior of telecommuters can theoretically be assessed against that of comparable non-telecommuters, but in practice it can be a challenge to identify an appropriately comparable control group.

In the present study, we will use four distinct methods of analysis. First, we will compare the changes in one-way commute length following residential or job relocations for telecommuters and non-telecommuters (defined in various ways), to answer the question: are telecommuters *moving* farther from work/home than non-telecommuters? If they are not (as was found in an earlier, short-term, study of State of California workers conducted by Nilles, 1991), the conceptual basis for inferring that telecommuting is stimulating further decentralization is undermined. If they are, on the other hand, it still remains to ascertain whether the increased commute length is caused by telecommuting, or whether telecommuting results from the move. Thus, this analysis does not address the causality question directly: if telecommuters are found

to be moving home and job farther apart than non-telecommuters, we still do not know if that is an effect or cause of telecommuting. It does, however, constitute a necessary benchmark against which to gauge the rest of the investigation.

In the second method of analysis, the timing of the moves in relation to the timing of telecommuting engagement is used to infer causality: temporal precedence of X over Y is generally viewed (where there is also conceptual and statistical justification) as strengthening the inference that X caused Y rather than the reverse (see, e.g., Baumrind, 1983; Holland, 1986). However, temporal precedence is not completely definitive, of course. For one thing, the timing might simply be coincidence, and neither event be related to the other. After all, people move closer to and farther from work all the time, for a variety of reasons that most often have nothing to do with telecommuting. Conversely, people telecommute for reasons having nothing to do with reducing travel, such as increasing their concentration (one-way commute distances as short as three miles have been reported by telecommuters in some studies).

Even if a relationship is present, it might not be the obvious one. If Y follows X, did X cause Y, or did the *anticipation of* Y cause X? Though the *implementation* of telecommuting may follow a residential move in time, the actual *choice* to telecommute may have preceded and prompted the move, and conversely, if a residential move followed a telecommuting episode, it is possible that the *decision* to move preceded and prompted the telecommuting.

To help address these kinds of ambiguities, one may say, “Why not just ask whether the move took place because of telecommuting?” The survey instrument used in this study does, in fact, directly ask respondents to rate the importance that telecommuting played in their relocation decision, and analyzing these responses is the third analysis approach we use. But these answers may not be reliable (though still worth examining) because respondents completing a survey regarding their telecommuting engagement may consciously or unconsciously report telecommuting as being more important than it really is, due to their heightened awareness of it.

The final method of analysis estimates linear regression models of the change in one-way commute duration and length following a residential relocation. The models consider the impact of socio-demographics, stated reasons for moving, telecommuting status, and work schedule, among other variables. The purpose of the modeling is to determine the relative importance of telecommuting status (before and after the move) while controlling for measures more traditionally associated with relocation decisions (e.g. the presence of small children), and to ascertain if the timing of the telecommuting engagement impacts the resulting commute characteristics. These models are less than ideal in that only the most recent residential relocations are considered – a necessary restriction as socio-demographic traits only available for the time of data collection are used to predict these relocation decisions made in the past.

These four methods – comparing the resulting commute characteristics following the relocation of telecommuters and non-telecommuters, assessing the timing of moves, examining the stated causality for the moves, and modeling the change in one-way commute length and duration – though each flawed in different ways, together should offer useful insight into the causal relationship between telecommuting and residential and job relocation. To the extent the multiple methods point to similar conclusions, our confidence in the result increases.

The organization of this report is as follows. The next section discusses the data in greater detail. Section 3 provides a detailed discussion of how the respondents are labeled as telecommuters (which is needed for comparing telecommuters to non-telecommuters) through time. Section 4 presents the first analysis: comparing the relocation patterns (both employment

and residential) of telecommuters and non-telecommuters. Section 5 addresses the issue of causality by investigating the timing of relocations in relation to the timing of telecommuting engagements. Section 6 examines the stated importance of telecommuting in the decision to make a residential move, as recorded in the survey instrument, and Section 7 presents linear regression models of changes in commute duration and length following a residential move. A concluding section ends the report.

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.*, forthcoming for further discussion on this issue, and on whether the non-telecommuters serve as an appropriate control group). An additional potential for bias is 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 socio-demographic characteristics of the sample are included in Table 1.

Table 1: Key Characteristics of the Sample

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

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

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 commute length, time, and 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.

In addition to the timelines, the survey collected data on attitudes toward telecommuting; reasons for, and other characteristics of, their three most recent residential and two most recent job relocations; impacts of telecommuting on relocations and vice versa; impacts of telecommuting on frequency and destination for a number of trip purposes; general transportation-related choices; job characteristics, home characteristics, and standard socio-demographic characteristics. The current study focuses on the information available from the two timelines as well as the questions about the role of telecommuting in relocations; 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. Over the 10-year period, these 218 individuals changed job locations only (i.e. no accompanying residential change) 171 times, changed residential locations only 198 times, and changed both job and residential locations in the same quarter 76 times. The focus of the analysis presented here will be on the changing commute characteristics of each move, comparing those characteristics between telecommuters and non-telecommuters, and the timing of those moves in relation to telecommuting engagement. Of course, as indicated earlier, the job and residential relocations examined could be taking place for any number of reasons, and may not even be the decision of the individual reporting the change (e.g. the spouse may be driving the residential move or a layoff may cause the job change). However, to the extent these varying circumstances are present in both the telecommuter and non-telecommuter samples, the differences between the two groups can be suggestively attributed to telecommuting.

3. Telecommuter Definitions

When comparing the behavior of telecommuters to non-telecommuters in the first part of our analysis, the means of labeling each individual, or more specifically labeling each individual in each time period, as a telecommuter or a non-telecommuter is very important. Various plausible definitions of telecommuter represent various expectations or hypotheses regarding behavioral differences. For example, it may be that those who are currently telecommuting behave differently than those who are currently not telecommuting. Or, it may be that those who have telecommuted in the past behave differently than those who have not. Or, it may be that those who at some point become telecommuters differ from those who never do.

To investigate these different potential behavioral influences of telecommuting on travel, we defined each individual during each time period (quarter-year) as a telecommuter or non-telecommuter in four distinct ways. Here, we present and briefly motivate each of the four definitions.

Definition 1: Current Telecommuter

The first definition labels an individual during each quarter-year as a telecommuter if she is actively engaged in a "regular" telecommuting episode (again, defining "regular" as "at least two days a month on average, for a period of at least three consecutive months") during that quarter. This definition allows for straightforward analysis: do those who are currently telecommuting behave differently, in terms of travel and relocation behavior, than those who are not?

Definition 2: After Telecommuter

The second definition can be re-stated, more directly, as, "once a telecommuter, always a telecommuter." After an individual has started telecommuting regularly, she is considered to be a telecommuter for each remaining quarter-year in the 10-year span. This definition is based on the concept that individuals, once exposed to telecommuting, may behave differently than those who have not yet tried it, or will never try it. It may be that individuals, once they telecommute, have a certain "footloose" location choice set, even though they may not be telecommuting at the time of their moves.

Definition 3: Before or After Telecommuter

The third definition is an expanded or "fuzzy" version of Definition 1. Here, an individual is considered a telecommuter during quarters in which he telecommutes regularly, as well as the single quarters before and after a telecommuting episode. This broader definition allows for the fact that major decisions, such as job and residential relocations, may take place over a period of time greater than a quarter-year; we want to allow the influence of telecommuting, if engagement started or ended around this time, to be considered as part of that decision. It also helps compensate for the use of discrete intervals to demarcate a timeline that is actually continuous. In other words, an individual may end a telecommuting engagement in one quarter and then change residences in the next, though the events could take place only a day apart.

Definition 4: Ever Telecommuter

The final definition broadens Definition 2. Here, if an individual engages in regular telecommuting at any point during the study period, she is considered to be a telecommuter for all quarter-years. Thus, alone among the four definitions, this definition is irrelevant to the timeline and holds at the individual (rather than the individual-quarter) level. This definition could be said to capture people who are prone to telecommute. It may be that some personality or other characteristics that drive them to telecommute may also drive them to engage in different types of travel and relocation behavior – independent of their current telecommuting engagement status. Of course, this definition will unavoidably erroneously classify some telecommuters as non-telecommuters, when their (past or future) telecommuting engagement takes place outside the 10-year study period.

Ironically, none of these definitions can be considered "definitive." Should one have to telecommute longer than one quarter before being labeled a telecommuter? Should a telecommuting episode have to overlap a specified length of time with a relocation before a relationship can be inferred? For example, if one stops telecommuting the quarter after a move, can it reasonably have been a cause of the move? What if a move prompts a telecommuting episode, but not until six months later? Our definitions do not resolve all possible difficulties, but given the arbitrary nature of any alternative requirements on telecommuting duration, the fact that different durations may be relevant for different people, and the limitations of the small

sample size, we focus on the four alternatives defined above. They span the spectrum from most conservative (Definition 1: Current Telecommuter) to most liberal (Definition 4: Ever Telecommuter), and together should bracket the range of plausible relationships.

4. Relocation Patterns of Telecommuters and Non-telecommuters

In this first stage of analysis, the residential and job relocation patterns (and, more importantly, the commute characteristics) of telecommuters (defined in the four separate ways presented in Section 3) and non-telecommuters are compared. The goal is to determine if telecommuters (both active and inactive), on average, select homes that are farther away from their workplaces, or choose jobs that are farther away from their homes than non-telecommuters do.

Table 2 cross-tabulates the resulting commute characteristics of telecommuters and non-telecommuters following residential moves made by respondents in the sample (those making "simultaneous" job and residential relocations, i.e. within the same quarter, are not considered in this analysis on the assumption – supported by Clark, *et al.*, 2003 – that such moves could differ importantly from residential-only moves, but without enough of them – only 2 of the 76 moves were made by telecommuters – to analyze separately). The table shows an overall average increase in one-way commute length and duration of about 2.02 miles and 2.40 minutes, respectively. This result is expected and indicates that the sample as a whole is increasing its commute length and duration following a residential move. Since the sample contains a minority of telecommuters, this result is a useful reminder that decentralization is by no means confined to telecommuters. The fact that the average changes in commute time and length are positive for the sample overall, and for the non-telecommuters as well as telecommuters, reinforces the observation that ongoing decentralization is occurring independent of telecommuting, and complicates the effort to separate any effects of telecommuting specifically, from this general trend affecting everyone.

When segmenting the sample based on telecommuting status, however, it becomes evident that telecommuters, on average, tend to move farther away from their workplaces than non-telecommuters. In each of the four definitions, telecommuters' moves result in greater commute durations than do non-telecommuters'; in all but Definition 2: After Telecommuter, a longer-distance commute emerges. The differences in commute characteristics are most pronounced using Definition 3: Before/After Telecommuter. However, this definition is perhaps the one most likely to confound cause and effect. Since the individual would be classified as a telecommuter the quarter before she actually started, if the residential relocation occurred in that prior quarter, it is more likely the move that prompted the telecommuting rather than the converse.

While the results do show a general trend of telecommuters relocating farther from their jobs than non-telecommuters, it should be noted that the differences between these groups are not statistically significant at the 95 percent confidence level – a result of the small sample size and relatively large variances in length and duration changes.

A more detailed cross tabulation of changes in commute distance following a residential move is presented in Table 3. Here, the sample is first segmented into Ever Telecommuters (those who at some point in the ten-year study period engaged in regular telecommuting) and Never Telecommuters (those who did not engage). Ever Telecommuters are then segmented further by the Current Telecommuter definition (as in Table 2) to distinguish between telecommuting and non-telecommuting quarters. This segmentation allows for a comparison among three groups: those who are currently telecommuting in a quarter of residential relocation, those who are not currently telecommuting but have telecommuted in the past or will telecommute in the

future (within the study period), and those who at no point in the study period telecommuted. We further segment moves by whether they are closer to work, farther from work, or the same distance away.

Table 2: Summary of Residential-Only Relocations by Telecommuters and Non-telecommuters

Telecommuter Definition	Status	Number of Moves[1]	Avg. Change in Cmt Length (mi)	Avg. Change in Cmt Duration (min)
Everyone	---	183, 181	2.02	2.40
1: Current Telecommuter	Telecommuter	19, 19	2.95	6.74
	Non-telecommuter	164, 162	1.91	1.89
2: After Telecommuter	Telecommuter	31, 30	1.06	3.00
	Non-telecommuter	152, 151	2.22	2.27
3: Before/After Telecommuter	Telecommuter	29, 29	5.76	7.93
	Non-telecommuter	154, 152	1.32	1.34
4: Ever Telecommuter	Telecommuter	72, 71	3.52	5.17
	Non-telecommuter	110, 109	1.02	0.70

[1] The numbers shown are the number of moves (not respondents) with valid commute length (first number) and duration data (second number).

Table 3: Differences in Residential Move Commute Characteristics among Current, Former/Future, and Never Telecommuters

Direction of move in relation to job location	Ever Telecommuter				Never Telecommuter	
	Current Telecommuter		Not Current Telecommuter			
	N[1] (%)	Delta length[2]	N (%)	Delta length	N (%)	Delta length
Closer	9 (47.4)	-13.1	18 (34.0)	-14.3	36 (32.7)	-9.2
Zero	2 (10.5)	0.0	7 (13.2)	0.0	27 (24.5)	0.0
Farther	8 (42.1)	21.8	28 (52.8)	16.3	47 (42.7)	9.4
All	19 (100.0)	2.95	53 (100.0)	3.72	110 (100.0)	1.02

[1] Number of valid commute length measures in each group; [2] Average change in one-way commute length, in miles, following a residential relocation.

Table 3 indicates that those who are currently telecommuting behave differently from those who never telecommute, but not that differently than those who telecommute at some point, yet are not doing so at the current time. The difference in change in commute length for those who are currently telecommuting and those who are not, but have in the past or will in the future, is rather small. In contrast, those who never telecommute have a much smaller average change in commute length than both of the other groups.

Table 3 shows that, ironically, for the two groups *not* telecommuting in the relocation quarter, moves were more often farther from work than closer to it, whereas Current Telecommuters moved closer to work about as often as they moved farther away. This picture shifts, however, when changes in the commute length itself are considered. For the Never Telecommuters, moves farther from work increased the commute by slightly more than moves closer to work reduced it, and there are enough more of the former that the net average change in commute length was one mile farther away. Similar but stronger patterns for the Not Current Telecommuters result in a net average increase of 3.7 miles. For Current Telecommuters, on the other hand, moves farther from work increased the commute substantially more than moves closer to work reduced it, but since the numbers of moves in each category are nearly balanced, the net increase is three miles, smaller than for the Not Current Telecommuters.

In sum, Current Telecommuters move farther from work relatively less often than do non-telecommuters, but when they do move farther away, it tends to be substantially farther away than non-telecommuters. The net change in commute length for Current Telecommuters falls between that of Not Current Telecommuters and Never Telecommuters. Again, however, the t-statistics comparing the overall means of these three groups show no statistical difference between any pair of groups at the 95 percent confidence level. Similarly, chi-squared tests show no statistical difference in the distribution among these groups at the 95 percent level (the moves were segmented within groups based on the distance of the moves, information not shown in Table 3), though the Current Telecommuter group is distributed differently from the Never Telecommuter group at the 90 percent level.

Overall, then, for those making a residential relocation, indications are that telecommuters are moving farther away from their workplaces than non-telecommuters, but the statistical evidence is relatively weak.

Turning now to job relocations, a similar set of analyses is presented. As mentioned before, individuals may have little to no control over a change in job location. However, to the extent that circumstances independent of telecommuting apply to each of the population segments, and we have no reason to believe they do not, we can infer that the differences in commute characteristics are related to telecommuting.

Table 4 presents the change in commute characteristics following a job relocation for telecommuters and non-telecommuters. It shows a pattern similar to Table 2, with a general trend of telecommuters changing to jobs which are located farther from their homes than non-telecommuters. This pattern holds for changes in commute duration for all definitions save Definition 4: Ever Telecommuter (which is the loosest definition); it holds for changes in commute length for Definition 1: Current Telecommuter (where the magnitudes of the differences are largest) and Definition 3: Before/After Telecommuter. Though a trend does appear, the differences between telecommuters and non-telecommuters within any definition are not statistically significant at the 95 percent confidence level.

Table 4: Summary of Job-Only Relocations by Telecommuters and Non-telecommuters

Telecommuter Definition	Status	Number of Moves[1]	Avg. Change in Cmt Length (mi)	Avg. Change in Cmt Duration (min)
Everyone	---	153, 153	1.95	1.89
1: Current Telecommuter	Telecommuter	16, 16	5.31	7.69
	Non-telecommuter	137, 137	1.55	1.21
2: After Telecommuter	Telecommuter	23, 23	1.57	3.83
	Non-telecommuter	130, 130	2.02	1.55
3: Before/After Telecommuter	Telecommuter	21, 21	3.05	4.52
	Non-telecommuter	132, 132	1.77	1.47
4: Ever Telecommuter	Telecommuter	72, 72	1.55	0.96
	Non-telecommuter	79, 79	2.25	2.59

[1] The numbers shown are the number of moves (not respondents) with valid commute length (first number) and duration data (second number).

In addition to comparing commute changes across telecommuter definitions, a closer examination of those who have engaged in telecommuting during the study period is presented in Table 5. Similar to Table 3, the analysis presented in Table 5 disaggregates the behavior of Ever Telecommuters by whether they are or are not engaged in a telecommuting episode during the job move quarter.

The table does present a general trend that those who are telecommuting tend to be selecting job locations farther away from their homes than those who are currently not telecommuting. However, the sample size is really too small to make any type of valid statistical inference.

To summarize, this section has demonstrated that during telecommuting episodes, telecommuters tend to select residential and job locations with more spatial and temporal separation than they do when not telecommuting and than Never Telecommuters do.

Table 5: Differences in Job Move Commute Characteristics among Current, Former/Future, and Never Telecommuters

Direction of move in relation to job location	Ever Telecommuter				Never Telecommuter	
	Current Telecommuter		Not Current Telecommuter			
	N[1] (%)	Delta length[2]	N (%)	Delta length	N (%)	Delta length
Closer	5 (31.3)	-11.2	20 (35.7)	-10.4	30 (38.0)	-11.1
Zero	3 (18.8)	0.0	10 (17.9)	0.0	10 (12.7)	0.0
Farther	8 (50.0)	17.6	26 (46.4)	9.0	39 (49.4)	13.1
All	16 (100.0)	5.31	56 (100.0)	0.47	79 (100.0)	2.25

[1] Number of valid commute length measures in each group; [2] Average change in one-way commute length, in miles, following a residential relocation.

5. Timing of Relocations and Telecommuting Engagement

The aim of Section 4 was to determine whether telecommuters, on average, choose to live and work farther apart than non-telecommuters, and it appears they do, although statistically the differences are not substantial. This section gets to the heart of the report: is the ability to telecommute causing this increase in length and duration (the "foe" scenario), or is telecommuting allowing less frequent commuting to take place for moves that would have happened anyway (the "friend" scenario)?

The timing of the residential and job moves in relation to the timing of telecommuting engagement is examined in an attempt to answer these questions. The causal inferences based on the timing of the relocation and telecommuting are summarized in Table 6. The rows in Table 6 represent the status of telecommuting engagement the quarter immediately preceding the relocation; the columns represent the telecommuting engagement status the quarter immediately following the relocation (we later informally examine periods of time around the move longer than one quarter). For example, if an individual is regularly telecommuting the quarter preceding a move (i.e. a Definition 1: Current Telecommuter) she is considered to be "telecommuting" before the relocation. If she is also telecommuting regularly the quarter after the relocation, she is considered to be telecommuting after the relocation, and would be placed in the lower-right hand element of the matrix. The telecommuting status the same quarter of the relocation is not considered, since it cannot be used to establish temporal precedence and since one's status during the periods before and after the move is arguably more relevant to the question of causality.

Each cell of the matrix allows for a different inference to be made about the causal relationship between telecommuting and relocation. Individuals who telecommute neither before nor after a relocation (the upper-left cell) presumably moved independently of telecommuting, and are referred to as the control group (i.e. non-telecommuters). Similarly, if a person telecommuted before, but not after a move (the lower-left cell), it is concluded that telecommuting did not influence the move (although the move may well have influenced the cessation of telecommuting); these cases are referred to as "telecommute quitters."

Table 6: Causal Inferences Based on Timing of Moves and Telecommuting Engagement

		After Relocation	
		Not Telecommuting	**Telecommuting**
Before Relocation	**Not Telecommuting**	No relationship (control)	Relocation caused telecommuting (beneficial)
	Telecommuting	No influence of telecommuting (telecommute quitters)	Telecommuting caused relocation (detrimental)

The key groups of interest are present in the right-hand side of the table. Individuals who do not telecommute before a move, but do telecommute after a move (the upper-right cell) are assumed (for the sake of discussion – as mentioned in the Introduction, this evidence is not definitive) to have their telecommuting engagement caused by the relocation. Conversely, those in the lower-right cell are assumed to have their relocation prompted by the ability to telecommute because they begin telecommuting, then relocate, and continue to telecommute.

After segmenting the sample into these four causal blocks, the number of moves and net changes in commute characteristics of each block, following relocation, can be examined. This summary for residential relocations is presented in Table 7. Each of the four blocks in the table contains the number of moves in each group, the resulting average change in one-way commute duration (in minutes), and the resulting average change in one-way commute length (in miles). Though the two key groups have small sample sizes (13 and 15 moves, respectively), the results could hardly be more disparate. Those who are said to have their telecommuting engagement caused by their residential relocation tend to move away from their workplace – increasing their commute time by about 18 minutes and their commute length 15 miles. In this scenario, an individual locates to a more distant residential location and presumably in response to the increased commute, begins telecommuting. Here, the telecommuting is a “friend” of travel-reducing policies, as the longer commute is relieved, to some degree, by telecommuting.

On the other side of the causal argument, those who are said to have their relocation caused by telecommuting actually tend to move *closer* to their workplace – an average reduction in commute time of 3 minutes and commute length of nearly 4 miles. Thus, in this possible “foe” scenario, the negative changes in commute duration make telecommuting at worst neutral to, and at best a friend of travel-reducing policies. It may be implausible to attribute this reduction specifically to telecommuting, but it is consistent (to the extent jobs are found in central locations) with the stereotype of the young, tech-savvy, telecommuter choosing to live in a more urban, central location (Ellen and Hempstead, 2002).

Table 8 presents a graphical representation of the residential relocation and telecommuting patterns of the sample, on which the results in Table 7 are based. The residential relocations are denoted by a two letter symbol (NN, YN, NY, YY), which correspond to the four causal groups discussed previously. Telecommuting engagements are denoted by solid black squares in each quarter where a residential relocation did not take place, and by a dark outline in the

quarters where a residential relocation did take place (only responses with a move relating to the two key causal groups are presented in the table).

In addition to offering an easy visual representation of telecommuting engagement and residential relocation through time, Table 8 also helps to validate the methodology used to segment the sample into causal groups. Recall, the causal segmentation was based solely on the telecommuting engagement status the quarter immediately preceding and immediately following the residential relocation. If, for example, an individual telecommuted a full year before the residential relocation, then only one quarter following the relocation, then had no more episodes in the study period, our methodology would have assigned this person the causal status of "telecommuting caused relocation", when, arguably, a more proper assignment would have been the status of "telecommute quitter", because the individual essentially quit telecommuting following the move. Instead of simply looking at the single preceding quarter and the single following quarter, some thought was given to examining multiple quarters before and after. Table 8 shows that doing so would not change a significant number of the causal assignments. Perhaps three moves, found in records 5035, 1030, and 5005, would arguably warrant having their causal statuses changed – to YY (from YN), NY (from YY), and YY (from NY), respectively. Changing these classifications would result in the outcomes shown in Table 9 – the substance of the findings remains intact.

Table 7: Changes in Commute Characteristics of Residential Movers Segmented by Telecommuting Causality Categories

		After Relocation	
		Not Telecommuting (N)	**Telecommuting (Y)**
Before Relocation	**Not Telecommuting (N)**	Control 148, 150 1.23 minutes 1.17 miles	Relocation causes telecommuting 13, 13 17.69 minutes 14.54 miles
	Telecommuting (Y)	Telecommute quitters 1, 1 45.00 minutes 34.00 miles	Telecommuting causes relocation 15, 15 -3.00 minutes -3.73 miles

Notes: N = no; Y = yes. The first row in each cell denotes the label given to the group; the second row contains the number of observations – first for change in commute duration, then length – in each segment; the third row contains the average change in one-way commute duration following a residential move; and the fourth row contains the average change in one-way commute length following a residential move.

Table 8: Temporal Incidence of Telecommuting Episodes and Residential Relocations

ID		1989				1990				1991				1992				1993				1994				1995				1996				1997				1998			
	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1030																																■	YY	■	■	■	■	■	■	■	■
1034													■	■	■		■	■	■		■	■	■		■	■	■		■	■	■			■	■		■		■	YY		■
1056																																NY	■	■	■	■	■	■	■	■	■
1059						■	■	■	■	■	■	■	■	■	■	■	YY	■	■	■	■	■	■	■		■	■	■				■	■	■	■	■	■				
2004								NN												■	■	■	■	■	■	■	■	■	■	■	■	YY	■	■	■	■	YY	■	■			
3007						NY	■	■	■			NN					NY	■	■	■	YY	■	■	YY	■	■	■	■	■	■	■	■					NN				
3010																						■	■	■	■	■	■	YY	■	■	■	■	■	■	■	■	■	■	■		
3020																					NY	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
4024																							NY	■	■	■	■	■	■	■											
5003									NN												NY	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
5004																					NY	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
5005									■	■	■	■			■	■	■	■	■	■	■		NY	■	■	■	■	■									■	■	■	■	■
5008	■	■	■	■	■	■	■	■	■	YY	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	YY	■	■	■	■	■	■	■
5035		■	■	■	■	■	■	■	■	YN			■	■	■	■	■	■	■	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	
5045																										NY	■				■	■			NY	■			■	■	YY	■
5047						NN								NN											NY	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
5048															NN																		NY	■	■	■	■	■	■	■	■
5057																								NY	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
5058														■	■	■	■				■	■	YY	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
5064																																		NY	■	■	■	■	■	■	■
5071		■	■	■	YY	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
5100				NN										NN		NN								NN						■	■	YY	■	■	■	YY	■	■	■	■	■

Notes: YY = telecommuting engagement one quarter before and after move; YN = telecommuting engagement before, but not after move; NY = telecommuting engagement after, but not before move; NN = not telecommuting before or after move; Dark box indicates telecommuting engagement the quarter of the move; solid square indicates telecommuting engagement in non-move quarters.

Table 9: Changes in Commute Characteristics of Residential Movers Segmented by Telecommuting Causality Categories with Manual Coding Changes

		After Relocation	
		Not Telecommuting (N)	**Telecommuting (Y)**
Before Relocation	**Not Telecommuting (N)**	Control	Relocation causes telecommuting
		148, 150	13, 13
		1.23 minutes	18.46 minutes
		1.17 miles	14.31 miles
	Telecommuting (Y)	Telecommute quitters	Telecommuting causes relocation
		0, 0	16, 16
		---	-0.63 minutes
		---	-1.19 miles

Notes: N = no; Y = yes. The first row in each cell denotes the label given to the group; the second row contains the number of observations – first for change in commute duration, then length – in each segment; the third row contains the average change in one-way commute duration following a residential move; and the fourth row contains the average change in one-way commute length following a residential move.

Turning back to job relocations, a similar causal analysis is presented; temporal precedence is again used. Even though changing jobs is a fundamentally different decision than changing homes (i.e. it often has a weaker connection to household needs, other than financial, and, in the case of layoffs or termination, may be done against the preferences of the individual), the use of temporal precedence to assign causality in the relationship between telecommuting and relocation is similarly applicable.

The job relocation data, segmented into the four causal groups, is presented in Table 10. Similar to the results found in the analysis of residential relocations, the “control” group (those not telecommuting before or after the relocation) are selecting jobs, on average, slightly farther, in terms of length and duration, away from home. Also, a relatively small number of observations are again found in the two key causal groups (“relocation causes telecommuting” and “telecommuting causes relocation”). The key difference is that for the job relocations, both causal groups have a larger increase in commute length and duration as compared to the control group. As such, telecommuting, by our causal assumptions, is both alleviating vehicle-miles traveled and potentially encouraging decentralization and increasing net travel amounts (depending on the relative frequency of the before and after commutes).

Table 10: Changes in Commute Characteristics of Job Movers Segmented by Telecommuting Causality Categories

		After Relocation	
		Not Telecommuting (N)	**Telecommuting (Y)**
Before Relocation	**Not Telecommuting (N)**	Control 124, 124 1.38 minutes 1.80 miles	Relocation causes telecommuting 7, 7 5.00 minutes 2.00 miles
	Telecommuting (Y)	Telecommute quitters 3, 3 -8.33 minutes -7.67 miles	Telecommuting causes relocation 10, 10 8.50 minutes 7.30 miles

Notes: N = no; Y = yes. The first row in each cell denotes the label given to the group; the second row contains the number of observations – first for change in commute duration, then length – in each segment; the third row contains the average change in one-way commute duration following a job move; and the fourth row contains the average change in one-way commute length following a job move.

6. Stated Importance of Telecommuting

The third method of analysis examines the stated importance of telecommuting to residential relocations. The survey instrument directly inquires about the importance of telecommuting to residential moves (but not job moves). Specifically, respondents could state that having the ability to telecommute was “most important”, “important”, “somewhat important”, or “not at all important” in their previous three residential relocations. We can then examine whether a high reported importance of telecommuting translates into a residential location more distant from the workplace. As discussed in the Introduction, these responses may be biased toward exaggerating the importance of telecommuting.

Table 11 presents the responses for the stated importance of telecommuting to the residential move decision, segmented by the four causal groups presented in Section 5. In addition to the number of moves in each cell, the average change in commute length is presented.

Table 11 suggests that, despite the presumed bias in favor, telecommuting does not play a very important role in residential relocation. Out of a total of 179 relocations, only 11 times did respondents rate the role of telecommuting as “the most important factor” (2 times), “important” (5), or “somewhat important” (4). Even among the 15 moves for which temporal precedence suggests a causal role for telecommuting (the “Yes, Yes” column), it is given some degree of importance to the move in fewer than half (7) of the cases – supporting the discussion in the Introduction of the point that temporal precedence by itself does not establish causality. However, those within that segment were considerably more likely to credit telecommuting (7 of the 11 “positive” responses mentioned above) than those who did not telecommute before the move, but did so following the move (2 of the 11). This result is consistent with the assumed direction of causality, based on the timing of the move and the telecommuting engagement,

made in the previous section. Also, the average changes in commute length for those respondents reinforce the previous unexpected result, that those who relocated their residence due to the ability to telecommute *reduced* their commute, on average. Of course, as noted earlier, the temporal precedence rule is also flawed in the sense that the actual timing of the *decision* (as opposed to the action) to telecommute and/or relocate is not known. As shown in Table 11, the two respondents in the "No, Yes" (relocation causes telecommuting) column who stated that telecommuting was "important" to their moves (even though they apparently did not start telecommuting until after the move) may be erroneously labeled by the temporal precedence methodology, which looks at the action (not the decision) of telecommuting and relocating. Because the average change in commute length for these two respondents is very high (48.50 miles), reassigning them to the opposing causal group could significantly change the results and present telecommuting as more of a potential "foe" to travel reduction policies.

Table 11: Stated Importance of Telecommuting in Residential Relocation Decision

Stated role of telecommuting in decision to move		No, No (Control)	Yes, No (Quitters)	No, Yes (Reloc->TC)	Yes, Yes (TC->Reloc)	Total
Not telecommuting at the time	N	16	0	3	1	20
	Avg. delta	4.25	---	-9.67	5.00	2.20
Not at all important	N	16	0	7	7	30
	Avg. delta	-0.05	---	4.00	0.00	0.80
Somewhat important	N	0	0	0	4	4
	Avg. delta	---	---	---	-11.50	-11.50
Important	N	0	1	2	2	5
	Avg. delta	---	34.00	48.50	-4.00	24.60
The most important factor	N	1*	0	0	1	2
	Avg. delta	-20.00	---	---	-7.00	-13.50
All (including never telecommuter responses**)	N	150	1	13	15	179
	Avg. delta	1.17	34.00	14.54	-3.73	1.91

Notes: "Yes, No" means telecommuting the quarter before the move and not telecommuting the quarter after, and so on. "Avg. delta" is the average change in one-way commute length (miles) following the move.

* We speculate that a telecommuting experience more than one quarter before the move influenced the move.

** In addition to the Never Telecommuters, this category also includes those Ever Telecommuters who did not answer the question on the role of telecommuting in their move (which accounts for the differences in this row and the sum across the preceding five rows).

Also of interest is the relationship between the change in average commute length and the stated importance of telecommuting on residential relocations, independent of the telecommuting status. The final column in Table 11 summarizes the average change in commute length and number of responses across the four causal groups. No obvious relationship exists between the average commute length change and the stated importance of telecommuting to the move. Those who were not telecommuting at the time of their residential relocation, or placed no importance on telecommuting to their move, increased their commute length by about the overall average, and those who placed an importance on the ability to telecommute did not uniformly move closer to or farther from work. Thus, whatever the *stated* role of telecommuting may have been, its *actual* impact on residential location appears to be neutral at worst and benign at best.

7. Modeling the Change in Commute Characteristics

To more formally quantify the role of telecommuting in residential relocation decisions, linear regression models of the change in one-way commute length and duration following a move are estimated. The purpose of the modeling is to determine the relative importance of telecommuting while controlling for other variables in the dataset that may traditionally be important predictors of change in commute length and duration (e.g. presence of children, desire for a bigger home) and to ascertain which of the telecommuting definitions (i.e. Current, After, Before/After, or Ever) most strongly impacts these measures. By allowing the temporally causal telecommuting definitions to enter the model, the causal relationships hypothesized in Section 5 may (depending on the results) be reinforced by the modeling.

One limitation of the modeling is that socio-demographic, work and home characteristic data was only collected at the time of the retrospective survey administration. As such, the data in these categories is not representative of the individual at the time of the relocation; it is representative of the individual in 1998. To help ameliorate this shortcoming, only the most recent residential relocation was considered in the modeling (the average time of the most recent move was 4.1 years before 1998, the standard deviation 2.8 years).

The variables included in the modeling fall into the following categories: telecommuting status, work characteristics, home characteristics, travel characteristics, reasons for moving, and general socio-demographics. A brief description of all the considered variables is as follows:

- Telecommute status:
    - based on the four definitions of telecommuting presented in Section 3;
    - based on whether telecommuting before the move or (in a separate variable), after the move;
    - based on the four temporally causal groups presented in Section 5;
- Work characteristics:
    - occupation type: management, professional, administrative, and other;
    - work schedule type: part-time, conventional, flex-time, compressed work week, and other;
    - duration with current organization and supervisor;
- Home characteristics (of the new residence):
    - duration at current home (how long ago the relocation took place);

- regional location in California (Sacramento or not);
- second home ownership;
- housing type: single family home, condominium, apartment, duplex, and other;
- presence of dedicated telecommuting space at the home;

- Travel characteristics:
  - current commute mode: automobile, non-motorized, or transit;
  - commute mode at previous residential location;
  - change in commute mode following the relocation (0-1 variable);
- Reasons for moving:
  - an important factor: my own job changed, job of household member changed, household size changed, was dissatisfied with home, was dissatisfied with neighborhood, wanted more room or different location for household activities, wanted to get closer to work, was dissatisfied with school, and other;
  - the most important factor (among the preceding list);
- General socio-demographics:
  - age, gender, household size, age of household members, number of workers, educational background and personal income.

Our *a priori* expectations were that variables in the socio-demographic, reasons for moving, and home characteristics would dominate the models of change in one-way commute length and duration. Specifically, we expected that households with young children, those stating a desire for "more room", and those moving to single family homes would move, on average, farther from work in terms of length and time. Due to the relatively low t-statistics presented in Section 3, we did not expect telecommuting variables to enter the models.

The model estimation results for the change in commute length and duration are presented in Tables 12 and 13, respectively. The two models are quite similar. The dominant variable in each of the models is the "wanted to get closer to work" stated reason for moving dummy variable. In both models, the coefficient on this variable is large and negative, indicating that those stating a desire to move closer to work are, in fact, moving substantially closer to work (in terms of time and distance).

The second variable common to both models is the flex-time work schedule measure. Those working a flex-time schedule (as opposed to traditional, compressed, or part-time schedules) tend to move farther from work than those working other schedules. This result suggests that those working flex-time may be able to avoid peak-hour congestion, and, in doing so, be able to live farther from work. Conversely, it may be that those who live farther from work may be adopting flex-time work schedules. This is an intriguing result, which calls for an investigation into the relationship between flex-time and residential relocation comparable to that being conducted for telecommuting.

The final significant coefficient in the length model holds a positive sign on the temporally causal telecommuting status variable, "not telecommuting before the move; telecommuting after the move." This result is consistent with the findings in Section 5 of those in the "relocation causes telecommuting" segment to be moving farther from work than those not in this causal group.

Table 12: Linear Regression Model of Change in Commute Length following a Residential Relocation (N=96)

Dependent Variable : Change in one-way commute length (in miles) following a residential relocation [-48,85]

Explanatory Variables	Coefficient	t-statistic	Beta
Constant	3.663	2.24	
Telecommute status			
Not telecommuting before the move; telecommuting after the move [0,1]	10.796	2.29	0.205
Work characteristics			
Flex-time employment type [0,1]	9.848	3.08	0.274
Stated reasons for moving			
Wanted to get closer to work (one reason) [0,1]	-23.606	-5.60	-0.510

[ ] = range of possible or observed responses

Adjusted R^2 = 0.266 (R^2 = 0.289) F-statistic = 12.50 (p = 0.000)

Table 13: Linear Regression Model of Change in Commute Minutes following a Residential Relocation (N=94)

Dependent Variable : Change in one-way commute duration (in minutes) following a residential relocation [-50,75]

Explanatory Variables	Coefficient	t-statistic	Beta
Constant	5.175	2.26	
Telecommute status			
Definition 3: Before/after telecommuter [0,1]	8.495	1.95	0.173
Work characteristics			
Flex-time employment type [0,1]	9.625	2.31	0.206
Stated reasons for moving			
Wanted to get closer to work (one reason) [0,1]	-32.475	-6.01	-0.539

[ ] = range of possible or observed responses

Adjusted R^2 = 0.281 (R^2 = 0.304) F-statistic = 13.10 (p = 0.000)

This finding supports the positive view of telecommuting. While taken at face value the model seems to suggest that telecommuting plays a more important role in relocation decisions than more expected variables, such as the presence of young children or a move to a single-family home, it is likely that household considerations are implicitly included among the reasons for wanting to get closer to work.

A similar result is found in the commute duration model. Here, a positive coefficient is estimated (with marginal significance) on the Definition 3: Before or After telecommuter status variable. This finding indicates that those who telecommute during the quarter of the move, or one quarter before or after the move, tend to relocate farther from work, in terms of time, than those who do not. Unfortunately, this finding does not help address the causal impact of telecommuting in that the temporal order of telecommuting and the relocation is not known.

However, it is telling that a telecommuting variable enters the model at all, especially in the presence of such a variety of other, more expected, variables.

8. Conclusion

This report presents an empirical examination of the causal relationship between telecommuting and residential/job relocation. The key question we attempt to answer is whether telecommuting is a "friend or foe" of travel reduction policies. In the friend scenario, telecommuting allows those independently inclined to live in distant locations to commute less frequently to work. In the foe scenario, telecommuting motivates those who would otherwise live closer to work to move to more distant locations, possibly resulting in more vehicle-miles traveled than would have occurred without the option of telecommuting.

The examination presented here used data from a 10-year retrospective survey of 218 State of California workers, including current, former, and non-telecommuters. We first confirmed that telecommuters, defined in four separate ways, are, in fact, putting more distance (and travel time) between their homes and workplaces than are non-telecommuters. While these results are not statistically robust due to the small sample size, they do provide suggestive evidence, and support further investigation into the causal nature of those observed differences.

Three additional methods were then used to examine the causal relationship between telecommuting engagement and residential/job relocation. First, the timing of the moves in relation to the timing of the telecommuting engagement was examined. Here, it is inferred that the ability to telecommute caused a relocation if an individual telecommuted directly before and after the move. Conversely, it is inferred that the relocation caused the telecommuting engagement if an individual began telecommuting following relocation. Those who neither telecommute before nor after the move are used as the control group, and those who telecommute before relocation, but not afterwards (labeled as telecommute quitters) are assigned to neither causal group. This analysis revealed that those who are inferred to have their residential relocation caused by telecommuting unexpectedly *reduce* their commute duration and length, on average. Conversely, those who are inferred to have telecommuting caused by their relocation substantially increase their one-way commute duration (by approximately 15 minutes) and length (18 miles). These results suggest that, on average, those who are inspired to move because of telecommuting are moving closer to work (or that the temporal relationship is largely coincidental, although as discussed below, the result holds even for moves in which telecommuting was directly reported to be important), while those who relocate far from work are afterwards inspired to telecommute.

For job relocations, the results differed slightly. Here, both key casual groups (those who are inferred to have their relocation caused by telecommuting and those who are inferred to have their telecommuting engagement caused by relocation) relocate, on average, to jobs farther from home.

The second method of causal analysis examined the stated reasons for residential relocations as captured by the survey instrument. In this analysis, the timing of the moves is again examined, this time in relation to the stated importance of telecommuting to the relocation. Here, though only small amounts of data are present, the results are consistent with the causal inferences made based on temporal precedence, in that those who are inferred to have their relocation caused by the ability to telecommute rated such an ability to be an "important" (to some degree) factor in their residential move more than those who are inferred to have their telecommuting caused by their residential move. Again, however, moves for the former group

tended to *reduce* commute lengths. There was no relationship between the "importance" of telecommuting in residential relocation decisions and the resulting change in commute length.

The final method of analysis estimated linear regression models of the change in commute duration and length following a residential relocation. These models considered a variety of variables, including telecommuting status, work characteristics, home characteristics, travel characteristics, and general socio-demographics. Because certain variables were only present at the time of data collection (e.g. general socio-demographics), only each individual's most recent residential relocation was considered (on average, 4.1 years before the time of data collection). The model of change in commute length included a significant coefficient on the telecommuting temporally causal status variable, "not telecommuting before the move; telecommuting after the move." This result buttresses the findings in the temporal precedence analysis, further supporting the idea that telecommuting is often triggered by distant relocations.

The results presented here more strongly support the hypothesis that telecommuting is a "friend" of travel reduction policies, with telecommuting more often following, rather than preceding, the relocations that lengthen the commute. Together with the finding from previous analysis of these data, that telecommuters' commute person-miles traveled is no worse than that of non-telecommuters' despite their longer one-way commute lengths (Mokhtarian, *et al.*, forthcoming), it appears that (at least for now) policymakers need not fear substantial "rebound effects" from telecommuting programs.

Given the limitations of our retrospective survey design and small sample, however, continued monitoring of the long-term impacts of telecommuting is clearly desirable. Ideally, future studies should perform a similar set of analyses on a larger sample of individuals, tracked over time, rather than surveyed retrospectively. Having a full range of socio-demographic and attitudinal data at each quarter, or other time interval, would allow for more complex and interesting analyses, including the impacts of telecommuting engagement on transportation attitudes through time; finer estimation of the relationship between telecommuting engagement and commute characteristics (i.e. after accounting for changes in income, lifestyle, etc., what role does telecommuting play?); and a mapping of telecommuting patterns of individuals over time (do they lose interest in telecommuting?). It would also be desirable to extend a similar analysis to home-based business owners, and (as mentioned earlier) to the relationship between flex-time and residential location.

References

Baumrind, Diana (1983) Specious causal attributions in the social sciences: The reformulated stepping-stone theory of heroin use as exemplar. *Journal of Personality and Social Psychology* **45(6)**, 1289-1298.

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

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

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

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

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

Holland, Paul W. (1986) Statistics and causal inference. *Journal of the American Statistical Association* **81(396)**, 945-960 (and comments by various authors immediately following).

Hollingworth, Brian J. and Eric J. Miller (1996) Retrospective interviewing and its application in study of residential mobility. *Transportation Research Record* **1551**, 74-81.

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

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

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

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

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

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

Mokhtarian, Patricia L., Gustavo O. Collantes and Carsten Gertz (2004) Telecommuting, residential location, and commute distance traveled: Evidence from State of California employees. *Environment and Planning A* **36(10)**, 1877-1897

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

Ory, David T. and Patricia L. Mokhtarian (2004) Does telecommuting really save commute time? Time, distance, and speed evidence from State of California Workers. Paper presented at 2004 Time Competition Workshop, Utrecht, the Netherlands, June. Available from the authors.

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

Shaw, Shih-Lung (2004) Spatial patterns of telecommuting in the Atlanta metropolitan area. Presented at ICT: Mobilizing Persons, Places, and Spaces. Doorn, the Netherlands, November 4-7.

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

Stough, Roger R. and Jean Paelinck (1996) Substitution and complementary effects of information on regional travel and location behavior. *Proceedings of the workshop on New International Perspectives on Telework*, Brunel University, West London, England, July 29-August 2, pp. 380-397.