

# **A Review of the Literature on Telecommuting and Its Implications for Vehicle Travel and Emissions**

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# **A Review of the Literature on Telecommuting and Its Implications for Vehicle Travel and Emissions**

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## **Abstract**

In this paper, we review 20 relatively recent empirical studies of telecommuting, all of which focus on the trip reduction perspective. The studies include earlier ones with smaller datasets, such as some pilot studies of individual employers, and more recent studies based on broader surveys of both telecommuters and nontelecommuters. We focus on the results of the studies with respect to participation and frequency of telecommuting, the effects on vehicle-miles-traveled (VMT) and trips, and in some cases, the impacts on emissions and air quality. Although there does not seem to be a consensus, there is a predominant view that certain factors increase both the likelihood of telecommuting and the frequency of telecommuting. These factors are having children in the household, being female, having more education, having a longer commute trip, having worked longer for one's current employer and/or in one's current position, and having a job that does not require face-to-face contact with coworkers or clients. Most studies of VMT and trip reductions from telecommuting show that telecommuters significantly reduce both daily trips and VMT. Not only does commute VMT fall, but noncommute VMT appears to fall in some cases as well. The studies of VMT, however, tend to focus on the reductions for individual employees who choose to telecommute. Although an individual telecommuter may experience a sharp reduction in VMT, total benefits depend on how many people are telecommuting, how often they are doing so, and the duration of telecommuting. More research is needed with larger and more broadly based datasets across employers that include both individual employee characteristics and employer and job characteristics. This would allow a better analysis of telecommuting choice and frequency as well as more reliable estimates of VMT and emissions impacts.

This discussion paper is one in a series of four RFF papers on telecommuting published in December 2004. Discussion papers 04-42 and 04-43 present analyses of two recent datasets on telecommuters. In 04-42, Nelson and Walls analyze data from five pilot cities enrolled in the "ecommuter" program. In 04-43, Safirova and Walls analyze data from a broad survey conducted by the Southern California Association of Governments (SCAG) of telecommuters and nontelecommuters. Finally, in 04-45 Nelson presents an assessment of institutional and regulatory barriers to using telecommuting in a mobile source emissions trading program. The studies by RFF are part of a larger report on the ecommuter program completed by the Global Environment and Technology Foundation (GETF) for the U.S. Environmental Protection Agency. More information about the overall project can be found on the ecommute/GETF website: <http://www.ecommute.net/program/>.

**Key Words:** telecommuting, mode choice, air quality, emissions

**JEL Classification Numbers:** R4, Q53, Q58

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# **A Review of the Literature on Telecommuting and Its Implications for Vehicle Travel and Emissions**

Margaret Walls and Elena Safirova\*

## **I. Introduction**

In this paper, we review the empirical literature on telecommuting from the trip reduction perspective. We focus on those studies that provide a general overview of the extent of telecommuting and trends in telecommuting, studies that statistically analyze the factors that determine the propensity of workers to telecommute and the frequency of telecommuting, and studies that focus on the impact that telecommuting has on vehicle miles traveled (VMT) and emissions. We do not review theoretical models (such as Safirova 2002), nor do we look at empirical analyses using data from outside the United States (as in Hamer et al. 1991). We also leave out research papers whose focus is other than the three areas we mention above. For example, we do not review studies that look at the effect that telecommuting has on individuals' quality of life (Vittersø et al. 2003), nor do we include anything related to workers' productivity, employers' attitudes, and other workplace concerns (Vittorio and Wirth 1990; Yen et al. 1994). We also do not review studies of such related issues as teleconferencing and teleshopping (Mokhtarian 1988). We do not discuss full-time long-distance telecommuting, hoteling, mobile work arrangements, and other less traditional approaches to work outside the office environment.<sup>1</sup> And finally, we do not look beyond telecommuting to other demand-management strategies for reducing travel.

The literature on telecommuting is extensive and has grown rapidly in recent years. Our review is not by any means exhaustive. Rather, we present a summary of some of the major published studies by recognized experts in the field, focusing to the greatest extent possible on

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<sup>1</sup> They are thought to be less relevant for reducing travel, and there are simply not enough data available to analyze them quantitatively.

more recent analyses and those with better and larger datasets. We mainly look at studies published in the primary peer-reviewed transportation and planning journals, with the inclusion of a few recent working papers. We avoid large reports, of which there are many, done for or by government agencies.

Datasets on telecommuting can be categorized mainly as either small but detailed datasets from pilot telecommuting studies for a single employer or datasets from large surveys of travel behavior, including telecommuting, across many employers. The former usually include details on the employer and job classifications, subjective information provided by employees, and travel diaries. However, the data can provide only a limited perspective on telecommuting because they focus on a single employer. The larger surveys, such as the Nationwide Personal Transportation Survey (NPTS), Census Bureau surveys, and some recent surveys by metropolitan planning organizations, cover a wider range of employers and jobs but usually have less information about those employers and jobs and usually don't include travel diaries. Almost none of the datasets track workers over time to see whether they continue to telecommute, change their telecommuting frequency, or drop out of the program altogether.

Nonetheless, several years of research covering a wide range of data provides a useful picture of the extent of telecommuting in the United States, some information about what factors lead people to telecommute, and some reliable information on the impacts of telecommuting on VMT and trip reduction. Section II below summarizes two studies that look at how telecommuting numbers are calculated and provide a broad picture of the extent of telecommuting in the United States. Section III focuses on the factors that explain telecommuting, and Section IV considers the VMT and emissions benefits from telecommuting. Section V provides some concluding remarks and highlights areas of future research needs.

## **II. Studies on General Telecommuting Statistics**

In this section of the paper, we summarize two articles that provide an overview of the extent of telecommuting taking place in the United States and its implications for reductions in vehicle miles traveled. Handy and Mokhtarian (1995) discuss the various ways that telecommuting is measured and the difficulties involved in comparing estimates from different surveys. In a transportation-centered definition of telecommuting, the crucial component of the definition is the elimination, or partial elimination, of a commute trip. Thus telecommuting is usually defined as working at home or at a telework center, or telecenter, as a substitute for going to an employer's workplace. Available data sources on telecommuting, however, have a variety

of problems. First, many surveys do not address telecenters at all, thereby leaving out workers who telecommute in that way. Second, some workers may telecommute part of a day and work in the office part of the day, thus shifting the commute time but not eliminating the trip entirely. These workers may be captured as telecommuters in a survey but should probably not be grouped with telecommuters who work at home for a full day.<sup>2</sup> Third, many surveys ask about working at home, thus possibly capturing a group of workers who are based at home. These are people who run home-based businesses or are independent contractors and who should probably not be counted as telecommuters.<sup>3</sup>

In addition to the issues associated with who exactly is a telecommuter, there are a variety of ways that the data from such surveys can be analyzed to provide information about the extent of telecommuting. The authors here distinguish between telecommuting *penetration*, the percentage of workers who telecommute, and the number of telecommuting *occasions*, the number of days on which an employee works entirely at home. Both statistics can be of use, but it is the latter that is critical for assessing the effects—VMT, congestion, emissions, and the like—of telecommuting.

Handy and Mokhtarian review the findings of four studies that provide information on telecommuting penetration. The national survey done by the Census Bureau finds that approximately 1% of California workers in occupations that are conducive to telecommuting report that they “usually” work at home. In an annual national survey, a private firm, Link Resources, finds that between 1.88% and 3.34% of U.S. workers telecommute. Two California surveys, one in the Los Angeles area and one in the San Francisco Bay area, focus only on full-time workers who work outside the home. The surveys find that the percentage of workers who “sometimes” telecommute is 9% for L.A. and 9.8% for San Francisco. These percentages are higher because they allow for the possibility of telecommuting only occasionally—as opposed to “usually” in the Census survey—and because they look only at full-time workers. Eight pilot studies suggest that telecommuting frequency (that is, average days per week spent telecommuting) varies widely. In the eight studies, the range is from 0.8 days a week to 3 days

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<sup>2</sup> See Safirova and Walls (2004) for analysis of a Southern California Association of Governments (SCAG) 2002 survey that appears to show that survey respondents reported telecommuting on days that they worked part of the time at their offices.

<sup>3</sup> The SCAG survey mentioned in the previous footnote is good in this regard because it asked specifically about home-based work as a separate category from teleworking.

a week. Finally, looking at the proportion of workers who telecommute on any given day across the four studies that focus on telecommuting penetration shows numbers ranging from less than 1% up to 2.1%—that is, on any given day of the week, between 1% and 2% of workers are telecommuting. A Caltrans survey provides the final estimate of the percentage of workers telecommuting summarized by Handy and Mokhtarian. It finds that on any given day, 1.47% of people in the workforce are telecommuting, 1.98% of people working on that particular day are telecommuting, and 2.01% of commute trips are replaced by telecommuting.

Pratt (2002) summarizes telecommuting statistics from questions added to several national surveys, including the Federal Highway Administration's Nationwide Personal Transportation Survey (NPTS) and the Census Bureau's American Housing Survey and Current Population Survey. Pratt points out some of the same issues identified by Handy and Mokhtarian. In particular, the amount of reported teleworking varies across studies because the sample of workers is often different. The percentage of the workforce who telecommute differs depending on whether the workforce surveyed includes self-employed people, independent contractors, part-time workers, and workers with more than one job. Samples that include self-employed workers, for example, or workers with multiple jobs often show a higher percentage of telecommuters. However, these people are not necessarily making fewer vehicle trips and traveling fewer miles. The NPTS shows that 15% of individuals who report that they worked from home within the past two months hold two or more jobs. The same survey finds that 22% of workers with multiple jobs telework, a much higher percentage than most studies report for workers overall or workers with one job. Pratt reports that surveys find that the work-at-home group consists of approximately 68% employees, 19% home-based business owners, and 11% non-home-based self-employed people.

Pratt compares numbers and trends over time for four surveys, and as expected, those surveys that include self-employed people show higher percentages of workers working at home. The number of telecommuters as a fraction of commuting employees is far lower. All surveys show a slight upward trend over time, with a leveling off in the late 1990s. Overall, Pratt finds that the various surveys show that telecommuting has been holding steady with about 16% to 17% of total workers working at home some of the time.<sup>4</sup>

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<sup>4</sup> At the same time, telecommuting dynamics might be broader than a mere percentage of telecommuters, since the enabling technology changed dramatically during the 1990s. Therefore, it is natural to expect different quantitative results of studies conducted a decade apart.

### III. Studies of Telecommuting Choice, Duration, and/or Frequency

We review seven studies of telecommuting choice, duration, and frequency. Two of these rely on stated-preference survey data rather than actual telecommuting behavior. The rest rely on surveys, including travel diaries, of actual telecommuting behavior as well as other mode choice information. Many of the earlier studies are limited to data from a single employer or, at most, two or three employers. Some of the more recent studies, however, draw on data from broad samples across a range of geographic locations and employers.

To look at factors that influence the likelihood of telecommuting, Yen and Mahmassani (1997) use a stated-preference approach, in which survey respondents are asked about their preferences and what they would do in certain circumstances, not what they actually do. They survey 545 employees in selected organizations in Austin, Houston, and Dallas.<sup>5</sup> The employees were presented with four alternatives: (1) not working from home at all, (2) possibly working from home, (3) working from home several days per week, and (4) working from home every day. The employees were also given seven program scenarios, which included 5% and 10% increases and decreases in salary and some increases in costs due to equipment purchases. The estimation results show, not surprisingly, that if the individual is given a salary increase when he telecommutes, he is more likely to telecommute, whereas a decrease in salary makes it less likely he will telecommute. If there are additional costs to working from home, the individual is less likely to telecommute. Employees with children under 16 at home are more likely to say that they would telecommute, as were those with personal computers at home and those with higher computer proficiency levels. The greater the distance from home to workplace, the more likely the employee is to say that she will telecommute. Among job characteristics, the authors find that the more face-to-face communication with coworkers that the employee says he needs, the lower the probability of telecommuting.

The results in the Yen and Mahmassani study need to be taken with a grain of salt, since they rely on stated preferences for telecommuting rather than actual behavior. As pointed out by Mokhtarian and Salomon (1996) in a study we review below, there is frequently a big difference between the two; survey respondents often say that they want to telecommute when in fact a small proportion of the population actually does so. Also, it is unclear whether Yen and

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<sup>5</sup> They do not explain how the organizations were selected or how the individual employees within those organizations were chosen.

Mahmassani have a random sample, since the authors do not say how they chose both the employers and the employees. There could be a serious sample selection bias in the study. And finally, in the questionnaire, the “possibly working from home” option is unclear, since it does not state a specific number of days per week. Without further clarification, it is not obvious to us what the authors mean by this option; if this is the exact wording on the questionnaire, it may not have been obvious to the survey respondents, either.<sup>6</sup>

Mokhtarian and Salomon (1996) survey 628 employees of the city of San Diego and ask about their preferences for telecommuting, perceived constraints on telecommuting, their actual telecommuting behavior, and sociodemographic data. In the survey of constraints to telecommuting that employees face, they find that 43.5% of employees report “job unsuitability” as a factor in their decision not to telecommute; 50.5% say “manager unwillingness” is a factor; and 4.3% say that a lack of awareness about telecommuting is a factor. A full 32% of the sample report that none of these three constraints hold.

In comparing preferences for telecommuting with actual revealed-preference outcomes, the authors find that although 88% of the survey respondents say that they would like to telecommute, assuming that they face no constraints to doing so, only 13% of the sample are currently telecommuting. The largest fraction of the sample, 56.5%, say they would prefer to telecommute but currently do not and also report that they face some constraints to telecommuting. The authors call this outcome the “preferred impossible alternative.” The next largest outcome, 18.5% of respondents, comprises people who say they would like to telecommute, face none of the listed constraints, but currently do not telecommute. The authors speculate that the workers face some other kind of constraint that is not included in the survey.

The authors state that there is usually an implicit assumption in telecommuting studies that every worker would like to telecommute if he could. They can look at whether this assumption is borne out in their survey responses. They find that only 3% of the sample report that they face no constraints to telecommuting but do not have a preference for it and do not

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<sup>6</sup> The study that initiated the stated preference approach is Bernardino et al. (1993). In a later work, Bernardino (1996) has applied the stated-preference method in a framework where employers are asked whether they would let their workers telecommute and workers are asked whether they would choose to telecommute under given scenarios. Although the quantitative results of the study are not of great interest because the stated-preference approach was used, inclusion of both the employer’s and the employee’s perspectives in the same framework deserves mentioning.

currently do it, thus confirming, in the authors' opinion, that most people would like to telecommute if they could.

Mokhtarian and Salomon do not conduct an econometric analysis of the data they collect, in which the effect that particular variables have on telecommuting behavior would be analyzed, holding other variables constant. They do show relationships between individual sociodemographic variables and stated telecommuting preferences, however. The data show that people who have longer commutes are more likely to report that they want to telecommute, as are women and younger people. Having children, however, seems to have no effect on the desire to telecommute. The authors do not report how these variables affect actual telecommuting behavior, just the reported preference for telecommuting.

Mokhtarian and Salomon's study is interesting because it tracks the relationships between actual behavior and stated preferences, but it is unfortunate that the authors do not look at the factors affecting preferences and actual behavior in an econometric model in which they can assess the effects of particular variables while holding constant other factors. It is difficult to know whether the relationships they say exist between telecommuting preferences and variables such as gender, age, and presence of children in the household would continue to hold if all variables were looked at simultaneously, as they should be.

Mannering and Mokhtarian (1995) use survey data collected from employees of three government agencies in California to model the frequency of telecommuting. Separate econometric models are estimated for the three agencies—one in Sacramento, one in San Francisco, and one in San Diego. In Sacramento and San Francisco, a large percentage of the surveyed workers telecommuted, between 42% and 46%, but in San Diego, the percentage was much lower, only 16.4%. In each case, the authors specify a multinomial logit model with three alternatives: never telecommute, telecommute infrequently (less than one day a week), telecommute frequently (at least one day a week). They state that they statistically tested whether pooling the data across the three groups is appropriate and rejected that hypothesis in favor of the separate models. In addition, they tested the validity of a nested logit model in which workers decide whether to telecommute at all and if so, determine the frequency of telecommuting, compared with the multinomial logit model in which the three frequency options are assumed to be independent. They statistically rejected the nested logit in favor of the multinomial logit for each of the three samples.

The model specifications and thus apparently the data available are different across the three samples. For example, number of people in the household is included as an explanatory

variable in the San Diego and San Francisco models but not in the Sacramento model. For Sacramento, the authors include household income, but this variable is not included in the other two models. Length of time the respondent has been in her present occupation and length of time with her present employer are included in the Sacramento model but not the other two. Many other variables differ across the models; in fact, there is very little overlap among the three.

Furthermore, as with some of the other studies we review here, the authors include, as explanatory variables, factors that are arguably endogenous. For example, the number of vehicles in the household is included in two of the models, as are indicator variables for whether the respondent has changed his mode of transportation or commuting time in the past year. The sample sizes for the Sacramento and San Francisco samples are quite small, 65 individuals in each, compared with 433 individuals in the San Diego group. For this reason, the Sacramento and San Francisco results should probably be viewed with some skepticism. And as with some of the other earlier empirical studies of telecommuting, one can draw only limited general conclusions based on the results from models estimated on data from a single government employer.

Although the authors do draw some general conclusions from their results, we choose not to summarize their statements here, as it is difficult to look across the three models with their different sets of variables. Instead, since the San Diego study has a relatively large sample size, we summarize the results of that model. The results show that being a mother of small children had a positive influence on telecommuting, as did the number of vehicles per capita in the household. The authors include many work-related variables in the San Diego model. The greater the number of hours worked, the less chance the employee telecommuted frequently. If the employee had worked unpaid overtime in the past six months, she was less likely to telecommute, and if she reported that she had taken work home in the past six months, she was more likely to telecommute. Perhaps somewhat surprisingly, if she reported that she supervised others in her job, she was more likely to telecommute. Also, if she reported that she had a good deal of control over her schedule, she was more likely to telecommute.

The authors also included some self-reported subjective indicator variables: on a scale of 1 to 5, the respondents were asked about their “lack of self-discipline,” their “family orientation,” and whether they were “satisfied with life.” The more a person reported that he lacked self-discipline and the greater his family orientation, the less likely he was to telecommute. The more satisfied he was with his life, on the other hand, the more he telecommuted.

Varma et al. (1998) is one of the few studies that looks at telecommuters over time and compares frequency and duration of telecommuting. In previous studies, dropout rates had been reported in the 32% to 41% range—that is, 32% to 41% of employees who telecommute stop doing so after some period of time.<sup>7</sup> Varma et al. report that the Mokhtarian and Salomon (1995) study of three California telecommuting programs found that of 180 telecommuters, 54, or 30%, had stopped telecommuting at some time in the past but had started again. Almost all who quit telecommuting did so for reasons related to their jobs or employers and not related to dissatisfaction with telecommuting or a change in their situations at home.

With these findings as background, the authors in this study use data from 15 telecenters operated as part of the Neighborhood Telecenters Project (NTP) in California, along with five non-NTP centers, to examine duration as well as frequency. Their study is the first look at such outcomes for users of telecenters. The sample they analyze includes a total of 274 telecommuters across the 20 centers, with the length of time that the centers had been in operation ranging from 16 weeks to four and one-half years. Their data on participation is fairly reliable because all telecenter users were required to log in when using the centers. Also, people who quit the program were asked to participate in an exit interview. The authors classify people as “quitters” if they had completed an exit interview and also if the last telecommuting date recorded was more than three times the average length of time between two successive telecommuting occasions for that person. Using these two metrics, the authors find that nearly 63% of the NTP telecenter users and 87% of the users of other telecenters were identified as quitters. Using a survival function, the authors then compute the probability that a given telecommuter will continue to telecommute beyond specific time periods. They find, for example, that there is a 56.7% chance that a person will telecommute beyond six months and a 94% chance that she will telecommute beyond six months *if* she has lasted five months. The median duration of telecommuting was nine months at NTP centers and eight months at non-NTP centers.

Varma et al. also look at the frequency of telecommuting for these telecenter users, both overall and in a comparison of quitters and “stayers.” They find that the weighted average frequency of telecommuting across both NTP and non-NTP centers was 22%, or about 1.1 days per week. Nearly 64% of the sample telecommuted less than one day a week. Lower

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<sup>7</sup> These findings are from the Puget Sound and State of California programs (see Henderson and Mokhtarian 1996, and Koenig et al. 1996).

telecommuting frequencies are associated with quitting: the average frequency of stayers was 1.4 days a week, while the average for quitters was about one day a week.

Finally, on the basis of the exit interviews, Varma et al. summarize the most commonly given reasons for quitting. As in the earlier studies cited above, the most common reasons were job related, followed by supervisor related. About 39% of respondents said they quit telecommuting because they changed jobs, left the organization they worked for, got laid off, found their job unsuitable for telecommuting, or had technological or cost-related problems. Just under 16% said that their supervisor either required or encouraged them to quit telecommuting or that they changed supervisors. Nearly 9% changed to home-based telecommuting, and 12% reported that the telecenter they had been using closed.

The Varma et al. study is very interesting because it is one of the few that focuses on dropout rates in telecommuting programs. Many studies show significant percentages of workers telecommuting, some of them doing so an average of two to three days a week, but most of these studies do not assess how this behavior changes over time. For purposes of congestion relief, VMT reductions, and air quality improvements, it is imperative that telecommuting be a sustainable outcome for a significant number of people. More studies like the one by Varma et al. are needed to look at telecommuting behavior over time.<sup>8</sup>

Wells et al. (2001) conduct surveys of employees at a public agency and a private firm in the Twin Cities area of Minnesota. They have a sample of 520 employees at the public agency and 276 at the private firm. Overall, 43% of the surveyed employees engaged in telecommuting: 45% at the public agency and 38% at the private firm. Workers at the public agency telecommuted, on average, nearly three days a week, and workers at the private firm telecommuted, on average, 1.92 days a week. Mondays and Fridays were the most common days on which workers telecommuted in the private firm, but there was no dominant day for workers at the government agency.

The authors collected sociodemographic information and information on travel behavior from both telecommuters and nontelecommuters. They also conducted face-to-face interviews with a small subset of employees, coworkers, and managers. Like Mokhtarian and Salomon, the authors of this study do not do a statistical analysis of their data. Rather, they simply report some

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<sup>8</sup> For summary statistics on dropout rates in five pilot cities in the federal government's "ecommuter" program, which are also high, see Walls and Nelson (2004).

summary statistics from their surveys. One strong finding they obtain is that the longer the commute, the more likely is travel behavior to change. Specifically, the longer the commute, the more likely the worker is to telecommute. The study did not find that telecommuters did more nonwork driving on telecommuting days; in contrast, results suggest that these workers tended to run errands on regular workdays and not on telecommuting days. The mode choice of telecommuters and nontelecommuters differed slightly: most individuals in both groups reported that they drove alone to work (74%), but nontelecommuters used the bus with greater frequency (13% versus 9%), and telecommuters carpooled more often (20% versus 15%).

As in other studies, Wells et al. find that the most common reason employees report that they do not telecommute is that their work requires face-to-face interaction with clients and/or coworkers. The authors find that telecommuters are more likely to be women, married, and have children.

Drucker and Khattak (2000) use the 1995 Nationwide Personal Transportation Survey (NPTS) to econometrically estimate the propensity to work from home. The NPTS provides a large national sample of individuals working a variety of jobs. It focuses on general travel behavior and vehicle ownership but also gathers a host of sociodemographic data and asks respondents how often they had worked from home in the previous two months. The choices available were two or more times per week, around once per week, once or twice per month, less than once a month, and never. Unfortunately, it is not clear whether these are true teleworkers who are avoiding a trip to an office by working at home as opposed to workers whose main place of work is at home. It is also not clear whether the sample includes workers with more than one job and/or independent contractors. Pratt (2003) highlighted these issues, as described above. However, Drucker and Khattak believe that the surveyed individuals were teleworkers, since answers to a separate question asking whether respondents “mainly” work from home overlapped almost not at all with the answers to the question about the frequency of working at home.

Although the NPTS contains a great deal of information on individual characteristics of the respondent, it does not include any job or employer information. This is a drawback of the survey for purposes of analyzing telecommuting behavior. On the other hand, the NPTS is one of the few large national samples available for study.

The results show that education, age, the presence of children in the household, gender, and certain measures of location and accessibility were all important in explaining the tendency to work at home. The greater the level of educational attainment, the more likely the individual

was to work at home. The older the individual, the more likely she was to work at home. Males were more likely to work at home than females, and people with children under the age of six were more likely to work at home than people without children. Larger household incomes increased the likelihood of working at home, but the marginal effects were relatively small. Respondents living in rural areas were more likely to work from home than those living in urban areas. Workers who must pay to park at work were more likely to work from home, and those with greater access to transit were less likely to work from home. The one unusual result in the study is the finding that distance to work is negatively correlated with working at home—that is, the farther the individual lives from his job, the less likely he is to work at home. This contrasts with results in many other studies. Perhaps if the study had limited its sample to metropolitan areas and/or used time to work rather than distance, the results might have been different.

The lack of information on job type and tenure, as well as employer characteristics, means that some of the individual characteristics in the model are probably proxying for other things. For example, the gender, age, education, and income variables may all be proxies for things like job tenure and whether the employee's position is a professional, management-level job. Ideally, one would have both individual variables, such as the ones included in this study, along with information about employers and jobs.

The authors estimate both ordered logit and probit models and a multinomial logit model, with qualitative results very similar across the models. They also perform a sample selection correction. Since they are using only the subsample of NPTS respondents who work either full- or part-time, they are excluding all nonworkers from the estimation. Yet these individuals may have preferences for or against working from home that would fail to be taken into account in a model that only used data from the nonrandom sample of working people. The authors simultaneously estimate a two-stage model that includes a selection equation that explains whether an individual works or not, along with the equation that describes the propensity to work from home.

Popuri and Bhat (2003) use data from a 1997–98 survey of 14,441 households in the New York metropolitan area conducted by the New York Metropolitan Transportation Council and the New Jersey Transportation Planning Authority. Travel diaries were completed by 11,264 households, and of these, the authors were able to use 6,532 employed individuals. In the final sample, 1,028 people—15.7% of the total—reported that they telecommuted. Among these, 54% telecommute, on average, once a week or less, 14.5% telecommute twice a week, 8.3% three times a week, and 23.2% four or more days a week.

This study estimates a model of telecommuting choice and frequency. In the estimation technique employed, the authors account for the fact that unobserved factors are likely to affect both whether to telecommute and how many days per week to telecommute. Results show that the following factors increase the likelihood that an individual telecommutes and increase the average number of days per week telecommuted: a college education, a driver's license, being married, working part-time, working for a private company (rather than government), and having to pay to park at work. The study also found that women with children are more likely to telecommute and do so more days per week, and women without children are less likely to telecommute. The higher the household income, the more likely the individual is to telecommute and the more days she does so. Also, the longer an individual has worked at her current place of employment, the greater the probability she telecommutes. Unfortunately, the authors do not have other job-related variables that would possibly be significant. This means that the college education variable, for example, is likely proxying, at least to some extent, for job type.

Popuri and Bhat include some variables in the model that are likely to be endogenous and should thus be omitted. These are dummies for whether the individual drives to work, takes transit to work, has a fax at home, and has multiple phone lines at home. The latter two may be jointly chosen along with the telecommuting decision, and the mode choice variables—the driving and transit dummies—obviously reflect decisions made by the individual that are likely to be functions of individual characteristics, such as education and income. The authors also include a dummy based on the answer to a survey question about whether “face-to-face interaction” is needed at work. It is possible that an individual who does not telecommute will answer this subjective question in the affirmative almost as a justification for his actions. Because these endogeneity problems will bias the results of the model, we must take some of the findings in the Popuri and Bhat study with a grain of salt. On the other hand, this is a large random sample across a wide variety of employers and includes nontelecommuters, and thus it has some advantages over some of the studies based on more limited datasets.

#### **IV. Studies Focusing on Vehicle Miles Traveled and Emissions**

Because telecommuting has the potential to reduce vehicle trips, miles traveled, and thus emissions of various pollutants, some studies have tried to quantify these benefits from telecommuting. We review six studies here that have this as their focus. An early paper by Kitamura et al. (1991) analyzes before-and-after behavior of 219 California state employees who telecommute. Three studies by Mokhtarian and coauthors rely on travel diaries in which workers filled out detailed information about their commute and noncommute travel patterns; these

studies include telecommuters who use telework centers as well as those who work from home. Unfortunately, however, the studies have very small sample sizes. Choo et al. (2003) take the unusual approach of looking at aggregate time-series data on VMT and telecommuting; this study takes a new perspective on the issue. Finally, a recent working paper by Collantes and Mokhtarian (2003) looks at VMT and person miles traveled (PMT) of telecommuters and nontelecommuters in a California sample over time, focusing on the links between residential location, VMT, and telecommuting. We review each of these studies in turn.

Kitamura et al. (1991) is one of the earliest studies to use travel diary information, which it gathered from participants in the State of California telecommuting study in the late 1980s. Employees and their household members filled out travel diaries before and after they started telecommuting; the sample includes a control group—also state government employees and their household members—who did not telecommute. The authors find that before the program began, those employees who eventually chose to telecommute made about the same number of trips per day as their counterparts who did not telecommute. Household members from the two groups also made about the same number of trips per day.<sup>9</sup> Once they began telecommuting, however, those employees made far fewer trips per day than the control group—an average of 1.94 versus 3.95 trips a day. Household members also made fewer trips per day, though the difference was smaller—3.08 versus 3.30 trips a day. Kitamura et al. find that, contrary to their expectations, there was no increase in noncommute trips by telecommuters. Most of the reduction in trips occurred during peak periods: the authors found that telecommuters made 73% fewer morning-peak departures after they began telecommuting and 54% fewer afternoon-peak departures.

The reduction in number of daily trips translates into a reduction in VMT as well. The average distances traveled per day by those employees who signed up for telecommuting dropped from 53.7 miles to 13.2 miles on telecommuting days. Compared with nontelecommuters, telecommuters were found to drive more miles per day, on average, when they were not telecommuting—56 versus 45 miles. This is consistent with the findings in many other studies that suggest that people with longer commutes tend to be the ones who participate in telecommuting programs.

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<sup>9</sup> The employees who ended up telecommuting and their household members actually made slightly fewer trips per day, but the difference is not statistically significant.

Finally, the Kitamura et al. study also looked at the mode choice of telecommuters and nontelecommuters. The percentage of total trips made per day that were car trips increased for the telecommuting employees once they began telecommuting but held the same over time for the control group: telecommuting employees' share of daily trips made by car rose from 81% to 91% when they started telecommuting.

Koenig et al. (1996) look at home-based telecommuters who participated in the State of California Telecommuting Pilot Project in the early 1990s. All individuals in the sample worked for the state government and filled out travel diaries before and one year after they began telecommuting. The study analyzed 40 people who chose to telecommute at home and 58 who didn't telecommute at all—that is, a control group. The authors found that the people who telecommuted reduced their average number of daily vehicle trips by 27% and reduced average VMT by 77%. Using California's EMFAC7 emissions model, the authors calculated that these reductions in driving resulted in substantial emissions reductions: 48% in total organic gases (TOGs), 64% in carbon monoxide (CO), 69% in nitrogen oxides (NO<sub>x</sub>), and 78% in particulate matter (PM). Comparing the telecommuters with the control group, the authors found that telecommuters, prior to joining the telecommuting program, averaged higher total VMT than nontelecommuters. This result appears to be due to higher noncommute VMT for this group, since telecommuters reported lower commute VMT than nontelecommuters. Most studies find that telecommuters have longer average commutes; thus, the participants in this study appear to differ from those in other studies.

Mokhtarian and Varma (1998) use data from another California telecommuting program, the Neighborhood Telecenters Project, which focused on the effectiveness of telework centers in reducing VMT and emissions. The project established 15 centers, and as in the previous study, travel diaries were filled out by participants and a control group of nonparticipants both before and after the telecommuting program began. For this analysis, however, the authors found that the sample size quickly became too small if they tried to analyze both groups before and after; the study therefore focuses only on the telecenter users and compares travel on days when they used the center with days when they commuted to work. The final sample included 72 people. They found that total VMT was 53% lower on telecommuting days than on nontelecommuting days, but the number of trips increased. This is because people apparently drive home from the telecenter for lunch. The authors use the EMFAC7 emissions model and find that emissions on telecommuting days are lower than those on nontelecommuting days by 15% (reactive organic gases), 21.5% (CO), 35% (NO<sub>x</sub>), and 51.5% (PM).

Henderson and Mokhtarian (1996) also focus on telecenters. Their data are from the Puget Sound Telecommuting Demonstration Project, sponsored by the Washington State Energy Office in 1990–91. The sample in this study includes 71 telecommuters—8 center-based and 63 home-based—and 33 nontelecommuters. The individuals worked for both government and private companies and, as in the other studies, kept extensive travel diaries on all commute and noncommute travel. Henderson and Mokhtarian found that total VMT for telecenter users dropped by nearly 54% on days when they used the telecenters compared with nontelecenter days. By comparison, home-based telecommuters reduced their VMT by 66.5% by working at home. Prior to the start of the telecommuting program, the telecenter users had the highest total daily VMT of the three groups, 91% greater than the control group. Home-based telecommuters had daily VMT 54% greater than the control group. Again in this study, emissions reductions were calculated. All pollutants were reduced, but NO<sub>x</sub> and PM decreased more than TOG and CO, since they are more directly linked to miles traveled.

Choo et al. (2003) take a very different approach to looking at the VMT impacts of telecommuting. They use national aggregate data to estimate an econometric time-series model of VMT as a function of economic variables; they then use the residuals from that regression—that is, the unexplained part of annual aggregate VMT—and regress them on telecommuting data. In the first-stage regression, the authors include as explanatory variables gross domestic product (GDP) per capita, the price of gasoline, average miles per gallon of the vehicle fleet, a consumer price index (CPI) for all commodities, and a CPI for transportation. They have 33 years of annual data, from 1966 to 1999, and their dependent variable is VMT per capita.<sup>10</sup> In the second stage, in which the authors estimate the first-stage residuals as a function of a constant term and the natural log of the number of telecommuters, results show the coefficient on the telecommuters variable as negative and significant.<sup>11</sup> The size of the estimated coefficient suggests that VMT during the sample period would have been approximately 2.12% higher than observed VMT in the absence of any telecommuting. The range across all the different VMT models estimated is 1.78% to 3.31%.

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<sup>10</sup> They estimate three versions of a VMT model and five versions of a VMT per capita model. The model we describe here is the one that they feel provides the best overall results.

<sup>11</sup> Regardless of the first-stage model used, the telecommuters variable is always significant in the second-stage model.

The Choo et al. study is interesting for its unique approach to estimating the VMT effects of telecommuting, but the aggregate data and simple version of the VMT model leave much unexplained. The residuals from the first-stage VMT model are likely to include the effects of several omitted variables; thus the telecommuting variable in the second-stage regression could be proxying for a number of other factors that affect VMT.

In a recent working paper, Collantes and Mokhtarian (2003) analyze data from 218 employees of the state of California. The survey of these employees, completed in 1998, included retrospective responses to questions about telecommuting frequency, commute distances, residential relocations, and job relocations for a 10-year period, 1988–1998, on a quarter-by-quarter basis. The point of the survey was to obtain some information on the relationships between travel behavior, telecommuting, and residential location decisions. In this paper, the authors do not econometrically model telecommuting choice or frequency or location decisions. They do, however, look at patterns of telecommuting over time and distances commuted and calculate total VMT and PMT for telecommuters and nontelecommuters.<sup>12</sup>

The authors find that average commute lengths, which increased over the 10-year period, are generally longer for telecommuters than for nontelecommuters and that the difference between the two increased over time. The authors speculate that two processes could be at work to cause these results: (1) relocations made for a variety of reasons could lead to longer commutes, thus prompting more telecommuting, and/or (2) increased availability of telecommuting might cause people to relocate farther from their jobs. The authors try to use their data to separate out these two possibilities. The second scenario—the availability of telecommuting leads people to move farther from their jobs—does not appear to hold. Current and former telecommuters in the dataset have shorter average commutes after a move, while nontelecommuters have longer ones. The longer-distance moves tend to be those that take place before telecommuting begins. The authors say that this suggests that telecommuting is a consequence of a move, rather than the cause of it. When survey respondents were asked what factors were important in their three most recent moves, telecommuting was listed in only 12 of 97 cases, and even in these, it was not listed as an important factor.

In terms of frequency of telecommuting, the data in this study show that people telecommute, on average, approximately 1.5 times a week. This average has fallen over time,

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<sup>12</sup> The two measures of miles traveled will differ to the extent that a person carpools.

according to the survey responses, and the authors explore different possible explanations for this decline. The most likely reason, according to the authors, has to do with the fact that the early adopters of telecommuting are those people who do it most often. The workers who adopt later are thus pulling down the average in the later years.

Combining the commute length with the frequency of commuting leads to an estimate of commute PMT. Average PMT has increased slightly over time, for both telecommuters and nontelecommuters. This is a result of longer commutes. Nontelecommuters have higher average PMT than telecommuters, but the difference declines in the later part of the sample period until the final three-quarters, when PMT is the same for the two groups. The same trends hold for VMT, but the difference between VMT for telecommuters and nontelecommuters is greater than the difference between PMT for the two groups. The authors look at VMT for respondents who reported “drove alone” as their commute mode and also at VMT for respondents who reported any commute mode that included use of a personal vehicle. Trends are the same for both measures of VMT.

Unfortunately, the study does not include travel diaries, so there is no measure of driving other than for commute purposes. Also, drawing conclusions on data based on survey respondents’ memories of their commute modes, distances, times traveled, and telecommuting behavior for each quarter up to 10 years ago is likely to be problematic. The attempt to obtain a time series of telecommuting and other data is laudable—no other study, to our knowledge, includes such information—but it would be better to survey workers contemporaneously over a period of time rather than rely on their memory.<sup>13</sup>

## V. Conclusions

The empirical literature on telecommuting has grown significantly over the decade of the 1990s and into the 2000s. With the availability of more and better data to analyze, published articles have proliferated. Early studies relied on relatively small samples of telecommuters and individual places of employment that had adopted organized telecommuting programs. Often these were state government agencies. Data collected often included information on only telecommuting frequency and commute VMT. Over time, studies grew to include

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<sup>13</sup> This is one virtue of the pilot “e-commute” program. See Walls and Nelson (2004) for analysis of three years of daily commute logs of participants in this program.

nontelecommuters as well as telecommuters, thus providing control groups with which to compare telecommuters' behavior. Newer studies also rely on travel diaries to track daily noncommute travel and often the travel of household members as well. In addition, sample sizes have increased over time. Some of the best studies now rely on very large surveys of individuals who work for a wide variety of employers and in a variety of jobs and locations.

Our focus in this review has been primarily on studies that look at the factors that explain telecommuting choice and frequency and the estimated effects that telecommuting has had on VMT and emissions. Although there does not seem to be a consensus, there is a predominant view that certain factors increase both the likelihood of telecommuting and the frequency of telecommuting. These factors are having children in the household, being female, having more education, having a longer commute trip, having worked longer for one's current employer and/or in one's current position, and having a job that does not require face-to-face contact with coworkers or clients. Many of these findings, however, are based on pilot studies of individual employers with relatively small samples of telecommuters. More research is needed with larger and more broadly based datasets across employers that include both individual employee characteristics and employer and job characteristics. Furthermore, more information is needed on telecommuting behavior over time. The Varma et al. (1998) study is very interesting because it provides some information on the duration of telecommuting. The authors obtain the somewhat troubling result that dropout rates are fairly high and the average length of time that employees telecommute is not that long. However, this study is only of telecenter users, not home-based telecommuters, and thus the results have limited applicability. More study of this important issue is crucial, especially since many metropolitan planning organizations in areas that violate the national ozone standard are beginning to include telecommuting as a significant source of emissions reductions.

Most studies of VMT and trip reductions from telecommuting show that telecommuters significantly reduce both daily trips and VMT. Not only does commute VMT fall, but noncommute VMT appears to fall in some cases as well. No study that we reviewed showed a significant increase in noncommute travel for telecommuters. Findings across the studies show that the average number of daily trips taken on telecommuting days is anywhere from 27% to 51% lower than on nontelecommuting days, and VMT is 53% to 77% lower. These reductions lead directly to significant reductions in organic gases, NO<sub>x</sub>, CO, and particulates.

Studies of VMT, however, tend to focus on the reductions for individual employees who choose to telecommute. Overall VMT and emissions reductions are equal to the reductions in VMT on telecommuting days multiplied by the number of telecommuters multiplied by the

average number of days each worker telecommutes. Thus, although an individual telecommuter may experience a sharp reduction in VMT, total benefits depend on how many people are telecommuting and how often they are doing so. And again, the duration of telecommuting matters as well: are people who report that they telecommute continuing to do so for months and years?

The literature on telecommuting is growing and improving as time goes on, interest in the subject grows, and more and better datasets become available to analyze. Future research will better capture the relative importance of work-related and individual-related variables in explaining telecommuting behavior across a wide variety of locations and employers. It will also focus some attention on the important issue of sustainability of telecommuting and what makes employees stay with telecommuting programs rather than dropping out.

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